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An Assessment of Non-Conventional Drinking Water Supplies in Remote Northern Alberta Communities

by

Tanya Faye Armstrong

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Environmental Science

Department of Civil Engineering

Edmonton, Alberta

Fall 1995

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **An Assessment of Non-Conventional Drinking Water Supplies in Remote Northern Alberta Communities** submitted by Tanya Faye Armstrong in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science.

Dr. Stephen J. Stanley

Dr. Daniel W. Smith

M. Joyce Relyea

Date: September 27, 1995

ABSTRACT

This thesis was completed as part of the Northern River Basins Study project. There were four types of research that contributed to the findings of this study. First, a *literature review* regarding the quality, sources, and utilization of non-conventional drinking water supplies in Alberta, and elsewhere, was carried out. Second, exploratory social scientific research was undertaken by *interviewing* several Northern Alberta residents regarding their drinking water quality concerns and non-conventional drinking water practices. Third, *samples of non-conventional drinking water were collected* and analyzed for various physical, chemical and microbiological parameters. The analysis done on the samples collected comprise part of the fourth area of research which was *laboratory work*. In addition to the lab analysis on the samples collected, several portable point-of-use drinking water treatment filters were also assessed in the lab. The results of each of these areas of research are discussed in this thesis.

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My foremost thanks go to Dr. Steve Stanley for his guidance and support in all aspects of this project, and especially for his faith in my abilities. I would also like to thank Dr. Dan Smith for his recommendations, and for the wealth of literature provided from his "office library."

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Without the assistance of the community members that acted as sampling guides during the field trips, many of the findings of this research project would have been unattainable. I am indebted to the following community guides for their knowledge regarding non-conventional sources of drinking water and for their recommendations on good sampling locations: Jumbo Fraser, Lesley Laboucan, Lester St. Arnault, Rosie Chalifoux, and Art Bingham.

Finally, considerable thanks is extended to the residents of the study area for allowing me into their communities and for sharing their *traditional knowledge* with me. I would specifically like to thank Lea Bill for her insights that helped to put this research into perspective. *Nanaskimwun.*

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
AO	Aesthetic objective
APHA	American Public Health Association
As	Arsenic, µg/L
ATCC	American Tissue Culture Classification
AWWA	American Water Workd Association
B	Boron, µg/L
Ba	Barium, µg/L
BDL	Below detection limit
Cd	Cadmium, µg/L
cfu	Colony forming unit
CHR	Community health representative
Cl_2	Chlorine, mg/L
Cr	Chromium, µg/L
Cu	Copper, µg/L
DI	Deionized
FC	Fecal coliforms, cfu/100 mL
Fe	Iron, mg/L
FS	Fecal streptococci, cfu/100 mL
GAC	Granular activated carbon
GCDWQ	Guidelines for Canadian Drinking Water Quality
Hg	Mercury, µg/L
HPC	Heterotrophic plate count, cfu/mL
IMAC	Interim maximum acceptable concentration
MAC	Maximum acceptable concentration
Mn	Manganese, µg/L
NRBS	Northern River Basins Study
NTU	Nephelometric turbidity units
PAC	Powdered activated carbon
Pb	Lead, µg/L
POU	Point-of-use
PFRA	Prairie Farm Rehabilitation Administration
RO	Reverse osmosis
TC	Total coliforms, cfu/100 mL
TCU	True colour units
THM	Trihalomethane, µg/L
THM-FP	Trihalomethane formation potential
TOC	Total organic carbon
TSA	Tryptic Soy Agar
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
WHO	World Health Organization
Zn	Zinc, µg/L

1. INTRODUCTION

1.1 Background Information

1.1.1 Conventional Drinking Water Supplies

Much of the raw untreated water that is available in Canada does not meet the limits established in health related drinking water quality guidelines. Therefore, before it can be considered a potable source of water, it must be treated. In many instances, particularly in larger settlements in Canada, drinking water has undergone considerable treatment in what can be called a *conventional drinking water treatment* facility. Although there are numerous variations and types of process components used, conventional treatment of surface water supplies typically consists of coagulation, flocculation, sedimentation, filtration, disinfection and distribution steps as illustrated in Figure 1-1.

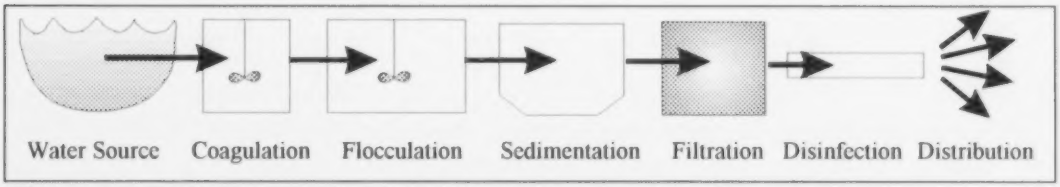


Figure 1-1. Typical Conventional Drinking Water Treatment Process Train

It should be noted that not all surface water supplies are treated exactly the same. The treatment processes used largely depends on the raw water characteristics as well as the level of treatment desired (Jacobsen, 1994). In some cases, the source water is of such good quality that some of the processes may be unnecessary. In other instances, processes are added to the treatment sequence for the removal of specific contaminants. However, some of the more sophisticated treatment techniques are not financially available for smaller systems with limited resources, hence reasonable alternatives are required to ensure an adequate and safe supply of drinking water (Drinking Water Health Effects Task Force, 1989). This is particularly the case for people living in remote areas in Canada.

1.1.2 Non-Conventional Drinking Water Supplies

Non-conventional drinking water treatment will be defined in this study as any treatment other than the conventional type of treatment described above. In many instances, the term non-conventional drinking water treatment can be used interchangeably with *point-of use drinking water treatment*. Some of these point-of-use technologies involve simple processes such as boiling, chemical addition, straining or aeration while other point-of-use technologies utilize more sophisticated devices based on disinfection or mechanical separation. A source of *non-conventional drinking water* then, is any water supply that has not been obtained directly from a conventional drinking water treatment facility. Some examples of non-conventional drinking water include self-hauled untreated surface water, well water, dugout water, rain water, bottled water, and water obtained from melted snow or ice, to name a few.

1.1.3 Northern River Basins Study

The Northern River Basins Study (NRBS) is a four and a half year study that is aimed at examining the relationship between development and the Peace, Athabasca and Slave river basins. The boundaries of the Northern River Basins Study enclose all areas that drain into the Peace River, Athabasca River and the Slave River. This includes a large proportion of Northern Alberta and parts of British Columbia, Saskatchewan and the North West Territories. The basins and boundaries of the NRBS study area are depicted in Figure 1-2. Eight scientific components have been set up to answer a series of guiding questions that are central to the Northern River Basins Study. These components are (1) Traditional Knowledge; (2) Other Uses; (3) Drinking Water; (4) Hydrology/Hydraulics/ Sediment; (5) Food Chain; (6) Contaminants; (7) Nutrients; and (8) Synthesis and Modelling. The Drinking Water Component has devised a number of linked studies to assess the quality of the drinking water in the NRBS area. This thesis was initiated as one of the studies of drinking water in the Northern River Basins Study area.

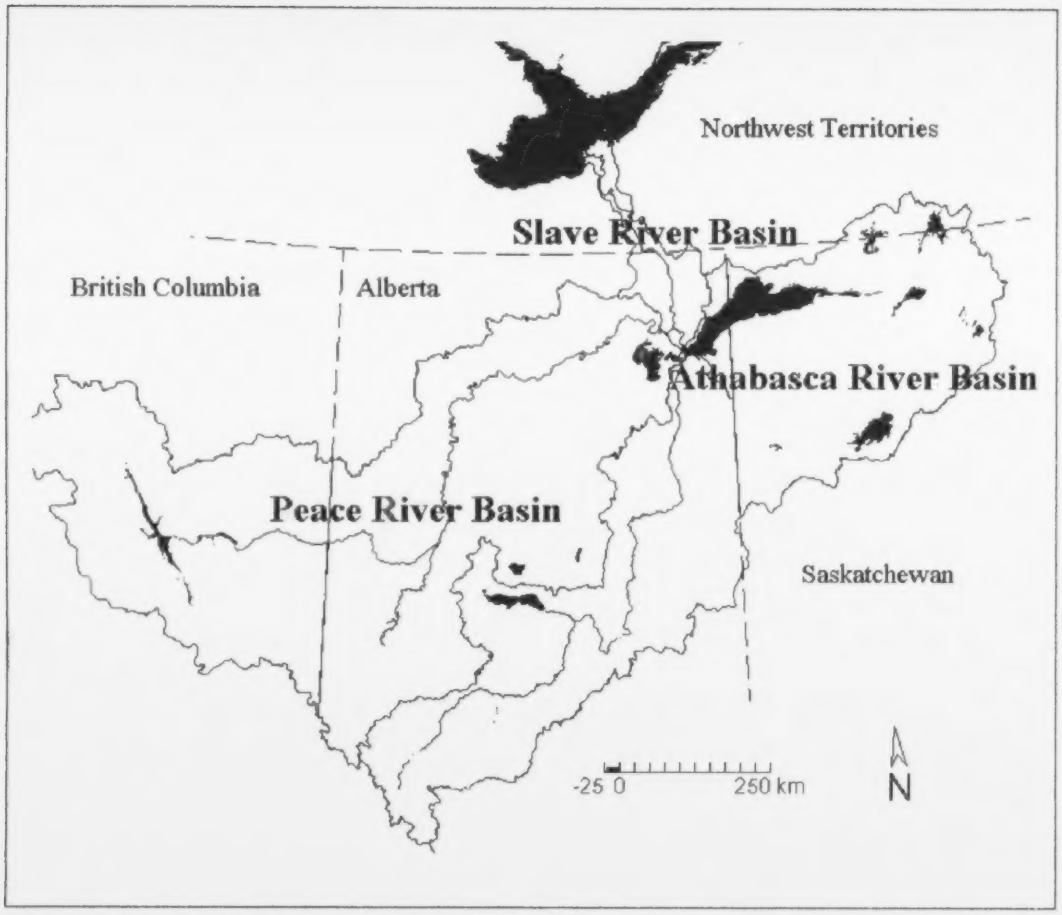


Figure 1-2. Northern River Basins Study Area.

1.2 Problem Statement

An initial review of pertinent literature found that little research has been completed in the area of non-conventional drinking water supplies compared to the well studied area of conventional drinking water treatment. This is interesting considering that there are many people living in rural remote areas in Alberta, and elsewhere, that do not have access to conventionally treated drinking water.

Using the Northern River Basins Study area as an example, the extent of the potential numbers of people that do not receive conventionally treated drinking water is illustrated:

- As of September 1994, the estimated population was 228 324 people living within the Alberta boundaries of the Northern River Basins Study area (Ellehoj, 1995).
- As reported by Prince *et al.*, (1994), it was found that approximately 171 362 of these people were reported to be receiving their drinking water from a conventional drinking water treatment facility.
- Based on these figures, 56 938 people, or approximately 25% of the residents of this area, do not receive their drinking water from a conventional drinking water treatment facility.

Consequently, in order to obtain safe potable water, people living in areas where conventionally treated water is unavailable must find an alternate source of drinking water and provide some form of treatment if necessary. Therefore, it is important to assess the utilization and quality of alternative drinking water sources in the study area, as well as the effectiveness of the non-conventional methods used to treat the water.

1.3 Objectives

The overall objective of this study was to assess the quality of non-conventional drinking water in remote northern Alberta communities. To meet this overall objective, a number of specific objectives needed to be met first. Listed below are specific objectives of the study:

1. Collect and compile existing information regarding non-conventional sources of drinking water, with particular reference to Northern Alberta. This involved a thorough review of available literature, as well as contacting numerous people involved in various aspects of drinking water supplies.

2. Determine the extent of utilization of non-conventional sources of drinking water in the study area. In addition to the population figures presented in the problem statement, an attempt was made to suggest a series of population sub-groups that may be particularly predisposed to using a non-conventional source of drinking water.

3. Visit some remote locations in Northern Alberta to interview residents regarding their source of drinking water with particular reference to their practice of consuming non-conventional drinking water. Information gathered from the interviews provided insight into the reasons people had for using non-conventional sources of drinking water and what sort of treatment, if any, was applied to the water supply prior to consumption.

4. Collect and analyze samples of non-conventional drinking water in the study area using the same method of collection and type of treatment as would be performed by non-conventional drinking

water users. Once the samples were collected, the water was assessed for various physical, chemical and microbiological parameters in a timely and appropriate manner in order to evaluate the quality of the water sample collected.

5. During the field work component, it was realized that many people in the study area may spend weeks at a time *living off of the land* without access to conventionally treated drinking water. Currently, there are portable water treatment filters on the market that claim to be suitable for expeditions such as these. Therefore, as a fifth objective of this thesis, three different types of portable point-of-use drinking water treatment filters were tested in the lab and assessed for their effectiveness and suitability for use in remote areas in northern Alberta.

6. The final objective of this thesis was to establish conclusions and recommendations for further study pertaining to non-conventional drinking water sources, quality, utilization and treatment options.

1.4 Methodological Overview

It was established early on that this thesis would be one of an exploratory nature. This was primarily due to the fact that previous research on non-conventional drinking water supplies and related water quality information was limited. Although there was some information on alternative drinking water supplies in the developing tropical world, very little information was found relating to northern populations. Nonetheless, many people working in related fields in government, industry and the private sector were contacted for their knowledge on the topic and a thorough review of the available literature was undertaken.

Once the initial information was collected, field trips were scheduled based on recommendations by the NRBS Traditional Knowledge Component leaders and other residents and government officials familiar with communities in the study area. Sites were primarily chosen based on the known utilization of non-conventional drinking water in the area and on the willingness of the community to accept drinking water researchers into the area. The areas chosen for site visits included isolated areas around Fort Chipewyan and remote locations near High Level, John D'Or Prairie, Fox Lake and Atikameg. Work in these communities was completed with the help of a representative guide from each of the respective areas. Upon arrival in the community, the objectives of the study were discussed with the guide. The guides in all of the sites visited proved to be extremely valuable due to their knowledge of community residents and their traditional ways. One of the main requests of the guide was to suggest names of people with whom he or she knew used a non-conventional source of drinking water. The next step was to contact these individuals and ask to meet with them to talk about their drinking water and perhaps collect a sample. The interviews were informal and the number of interviews at each site was very limited due in the most part to the short period of time spent in the communities. However, insight into many people's viewpoints was obtained even though there were several limitations with this method of interviewing. These viewpoints and limitations are discussed in subsequent sections of this thesis.

One of the primary objectives during the field trips was to collect samples of non-conventional drinking water. Samples of water were taken from locations suggested by local people as sources of non-conventional drinking water. These samples were analyzed for various physical, chemical and microbiological parameters in a laboratory setting following the procedures outlined in Standard Methods for the Examination of Water and Wastewater (APHA *et al.*, 1992). Most of the physical and chemical parameters were analyzed in the field at the time of collection. However, some parameters could not be analyzed in the field and samples were transported back to Edmonton for further analysis. Samples were sent to the University of Alberta

Environmental Engineering lab within 24 hours for microbiological analysis. Metals analysis on the samples using Atomic Adsorption technology was done by a private lab.

Based on the information gathered from residents during the first two field trips, it was found that many of those interviewed spent a portion of their time "living off the land" in various capacities such as hunting, fishing, and trapping to name a few. When asked what they drank during these expeditions, many people responded that they would drink untreated water right from the river or lake. Although it was not determined whether or not this contributed to an illness, the risk of a gastrointestinal disease from consuming contaminated water is high in such a situation. Therefore, three different types of portable drinking water treatment filters were assessed in a laboratory setting to determine if units such as these may be suitable treatment options for people involved in traditional living off the land activities. An appropriate protocol was developed to test the units by challenging them with a test water that had a high turbidity and a high microbial count. Appropriate tests were performed on the influent and effluent stream and removal rates for each unit were calculated.

Finally, the results were analyzed for each aspect of study including the literature review, the field trip interviews, water sample analyses and the portable filter assessment. Conclusions and recommendations for further study were then established for this thesis.

2. LITERATURE REVIEW

2.1 Drinking Water Quality and Health

Water is a basic human need and it is essential to sustain life. The World Health Organization (WHO) has defined health as a fundamental human right for a state of complete physical, mental, social and spiritual well-being (WHO, 1978). The links between water and health are numerous and the interactions are complex (WHO, 1993). It has been stated that an adequate supply of safe water is a prime requisite in the maintenance of good health (WHO, 1978; Health and Welfare Canada, 1973).

A person's health can be compromised by drinking water if the quality of the water is poor or if the quantity of water for consumption is inadequate. It is known that enteric diseases are generally related to poor water quality whereas diseases of the skin are related to limited water quantity and availability (Brocklehurst *et al.*, 1985). The average daily consumption of drinking water for a Canadian adult is about 1.5 litres a day (Environmental Health Directorate, 1991). This consumption rate varies widely among individuals depending on attributes such as body weight, ambient temperature, diet, activity, culture, clothing and health status (McJunkin, 1982). If an average person is assumed to live for 75 years, that means that a person would consume approximately 43 172 L of water in his or her lifetime. From this, it can be seen that water can be an important vehicle for contaminants to enter our body. Therefore, not only is water physiologically necessary for survival, but the physical, chemical and microbiological constituents of the water that are consumed can significantly impact a person's health.

2.1.1 Waterborne Diseases

Waterborne diseases are illnesses in which a pathogen (a disease causing agent or microorganism) enters the body as a passive component of drinking water. "Waterborne diseases can be further categorized as those due to microbiological organisms and those due to inanimate toxic substances suspended or dissolved in the water (McJunkin, 1982)." Microbiological waterborne diseases are generally acute and episodic, whereas illnesses caused by chemical agents may be acute, but normally result from long term ingestion at low concentrations.

Waterborne "diseases caused by pathogenic bacteria, viruses, and protozoa or parasites are the most common and widespread health risk associated with drinking water (WHO, 1993)." Sources of these waterborne organisms in a watershed include discharges from humans, wild and domestic animals, industry and storm water runoff events (WHO, 1993; Geldreich, 1991). The transmission of waterborne disease can be by primary or secondary routes. The primary route of infection is through the direct consumption or inhalation of water that contains the pathogen. Secondary routes of infection occur by consuming food that is washed by contaminated water or through contact with an infected individual (Emde *et al.*, 1994). Disease causing microorganisms can be further classified as being direct or opportunistic pathogens. Direct pathogens can cause disease in a normal healthy individual. On the other hand, opportunistic organisms generally form part of the normal micro-flora of the body, but given the correct conditions, may be capable of causing an infection in a compromised individual (Geldreich, 1991).

A list of microbial pathogens that may be found in Northern Alberta waterbodies is presented in Appendix A. Information on the pathogenicity, infectious dose, range of symptoms, potential risk groups, and vehicle of transmission is included for each microorganism.

Despite the vast numbers of bacterial, viral and protozoan organisms that are known to cause illness if consumed in sufficient quantities, there are still many unknown microbiological agents of disease. There are also many cases in which an individual is sick and may have many of the symptoms described above, but for which the etiology of the illness is unknown. In the 1986 to 1990 notifiable disease statistics for Alberta analyzed by Emde *et al.*, (1994) one of the categories was "Unspecified Diarrhea". This means that an individual presented to the health care facility with diarrheal symptoms, but the exact cause of the diarrhea was not determined. This could be because, stool and water samples were never investigated and if they were, it could be because an etiological agent was not detected. Furthermore, microorganisms are not the only agents that are responsible for diarrhea. Sometimes, excessive physical and chemical constituents of a water supply can also cause such symptoms. However, due to the sheer number of potential physical and chemical contaminants, interested readers are referred to Chapter 2 of the fourth edition of Water Quality and Treatment: A Handbook of Community Water Supplies (AWWA, 1990) for more information.

2.1.2 Drinking Water Quality Guidelines

As a result of the wide variety of waterborne illnesses that can result from consuming contaminated drinking water, considerable effort has gone into the establishment of drinking water quality guidelines. The World Health Organization has established drinking water quality guidelines intended to be used in the development of national standards worldwide (WHO, 1993). The United States Environmental Protection Agency (USEPA) has some rigorous drinking water quality guidelines and Canada has the Guidelines for Canadian Drinking Water Quality (GCDWQ) (Federal-Provincial Subcommittee on Drinking Water, 1993). The province of Alberta has adopted the GCDWQ in the regulation of drinking water quality (Prince *et al.*, 1995; Alberta Environment, 1988). The GCDWQ has established limits for various physical, chemical,

microbial and radiological parameters. It is assumed that if the water supply in question meets all of the recommended levels set in these guidelines, that the quality is good, and that the water is safe to drink.

Within the GCDWQ, a parameter is assigned a limit if the assessment of data on the contaminant of concern indicates a need to set a numerical guideline on the constituent; for health or other reasons. Maximum Acceptable Concentrations (MAC) have been established for certain substances that are known or suspected to cause adverse effects on health (Federal-Provincial Subcommittee on Drinking Water, 1993). MAC's are derived to protect health based on the assumption of lifelong consumption of the substance at the established guideline concentration. Interim Maximum Acceptable Concentrations (IMAC) are set for substances that are assumed to have an adverse effect on health but for which there is insufficient toxicological data to set an MAC with reasonable certainty. Larger safety factors have been employed to compensate for the uncertainties for these substances. Aesthetic Objectives are applied to parameters that affect the acceptability of the water by consumers and so that a good quality of water can still be supplied. A summary of the Guidelines for Canadian Drinking Water Quality is presented in Appendix B.

It is evident from Appendix A that the potential number and types of pathogens in a water supply is extensive. Although techniques are available to enumerate most of the common types of pathogens found in water, due to the large numbers and types that can be found, this is not always practicable when monitoring drinking water quality (McJunkin, 1982). Therefore, in the assessment of the microbial quality of potable water, indicator organisms are used as an indirect measure of pathogens in the water. At least three simple requirements should be satisfied in order for an agent to be considered an indicator organism. First, indicator organisms should be present in sewage and polluted water where pathogens are present. Second, the population of indicator organisms should be correlated with the degree of pollution. Third, indicator organisms must be easily and

quickly identified and enumerated in simple lab procedures (McJunkin, 1982). The coliform group of bacteria are the indicator organisms assessed in the GCDWQ.

Total Coliform (TC) organisms are gram-negative, rod shaped bacteria that ferment lactose at 35°C to 37°C with the production of acid, gas, and aldehyde within 24 to 48 hours and are capable of growing in the presence of bile salts (McJunkin, 1982). Coliform bacteria are members of the *Enterobacteriaceae* that are usually found in the intestinal tract of warm-blooded animals. Thermotolerant Fecal Coliforms (FC) are a subset of the Total Coliform organisms that can ferment lactose at 44°C to 45°C including the *Escherichia* genus and to a lesser extent species of *Klebsiella*, *Enterobacter*, and *Citrobacter*. Monitoring for both TC and FC is required in the GCDWQ.

The GCDWQ also requires that the general bacterial population is assessed even though this general bacterial enumeration does not usually have a direct health significance (McFeters, 1990). The reason that it must be monitored is because excessive bacterial concentrations can hinder the recovery of coliforms, therefore preventing the detection of a potential health threat (Federal-Provincial Subcommittee on Drinking Water, 1993; McCabe and Winton, 1990; McFeters, 1990). The Heterotrophic Plate Count (HPC) is one method of enumerating the general bacterial population. The HPC is a measure of aerobic and facultative aerobic bacteria found in water (McFeters, 1990).

It has been argued that the limited coliform monitoring requirement in the GCDWQ is insufficient in terms of protecting public health. This is because there is a large spectrum of organisms that can survive conventional treatment processes including spore formers, acid fast bacilli, pigmented organisms, disinfectant-resistant bacterial strains, various yeasts, fungi, and actinomycetes (AWWA, 1990). Therefore, sometimes, the regular coliform enumeration is supplemented by further microbiological assays. Currently, viruses and protozoa are under review for possible addition to the GCDWQ (Federal-Provincial Subcommittee on Drinking Water, 1993).

2.1.3 Drinking Water Quality in the Study Area

No information was found related to historical drinking water quality data for non-conventional drinking water supplies in the study area. However, a 1994 Drinking Water Component Report compiled, synthesized and summarized existing drinking water quality data for conventional drinking water treatment facilities in the NRBS area (Prince *et al.*, 1994). In this study the analysis of data in the Treated Water Survey showed that chemically, the drinking water in Northern Alberta meets health related guidelines with the exception of some trihalomethane and a few 2,4-dichlorobenzene violations (Prince *et al.*, 1995). It should be noted that the Treated Water Survey did not include monitoring of microbial contaminants. To assess the microbial quality of drinking water in the same area, a follow up study by the same researchers was undertaken. Work carried out in this study involved analyzing historical Total and Fecal Coliform data, historical turbidity data and samples obtained from site visits to 38 facilities in the study area (Prince *et al.*, 1995). It was found that "small facilities produce poorer drinking water quality than larger facilities" and several small facilities have microbial counts that exceed values suggested in the GCDWQ (Prince *et al.*, 1995).

2.1.4 Health in the Study Area

As mentioned, the World Health Organization (WHO) has defined health as a fundamental human right for a state of complete physical, mental, social and spiritual well-being (WHO, 1978). Therefore, determining the health of an area is a very complex task that requires an in-depth analysis of many factors of life of the people it is trying to assess. The Human Health Committee of the Northern River Basins Study is involved in a Human Health Study that is set up to assess the health in the Basins based on the analysis of health records (Huberman, 1995). However, the results of this study were unavailable at the time that this thesis was written.

In a 1994 Health Records Study by Emde *et al.*, it was found that there appeared to be a higher incidence of selected waterborne diseases in some of the study area's Health Units compared to the provincial averages. It was concluded that "although incidences of some diseases were higher, in many cases the differences were not significant and residents generally do not appear to have substantially higher risks from waterborne diseases in the study area compared to the rest of Alberta (Emde *et al.*, 1994)". This conclusion was reached based on the assessment of health record data from seven Alberta Health Units and Annual Notifiable Disease Summaries provided by Alberta Health. The main limitation with this was that Health Canada records were not included in the analysis. It is very likely that the conclusions may have been different if the Health Canada databases had also been assessed because there is a high native population in the study area and health care on the reserves is administered by Health Canada (Bingham, 1994).

There are many Indian Reserves in the study area and therefore a significant proportion of this population is of native descent. It is well established that the native population in Canada experiences more ill-health than the rest of the Canadian population (Fraser-Lee and Hessel, 1994; Robinson and Heinke, 1990; Weller and Manga, 1987). Life expectancy for native Canadians is ten years less than the national average, and the infant mortality rate is more than double the rate for Canada as a whole (Fraser-Lee and Hessel, 1994). Epstein (1982) has likened the health of the Native population to that of "developing societies within developed countries" and Postl *et al.*, (1987) observed that the health of the Canadian Aboriginal people is "perhaps the largest public health problem our country faces (Fraser-Lee and Hessel, 1994)."

However, results from a Traditional Knowledge survey administered in the study area showed that "overall, respondents tended to be positive about their health with an average rating of 2.8 on a scale of one (excellent) to five (poor) (Traditional Knowledge Component, 1995)." Respondents in this survey were asked to cite any illnesses that were increasing or decreasing in their communities. The most common responses were an increase in cancer (59%), an increase in diabetes (25%), and an increase in heart

problems (17%) (Traditional Knowledge, 1995). So, although the majority of the First Nation's people interviewed in this survey rated their own health positively, many of them also indicated a rise in several diseases in their communities. It was also found in this survey that over half of the respondents felt that their health or someone else's health had been affected by water quality.

Some of the people that were interviewed by the Traditional Knowledge Component no longer consume lake or river water. Almost half (49%) of the people that fit into this category (of no longer consuming lake or river water) associate some sort of disease or ill-health with the consumption of lake or river water. Therefore, it can be deduced that some NRBS residents do recognize the link between drinking water quality and health.

The importance of good drinking water treatment in order to meet drinking water quality guidelines is very important in the protection of public health. This can be accomplished in one of two ways. First, for larger communities, water can be treated in conventional drinking water treatment facilities. Second, for those people who live in remote locations, smaller quantities of water can be treated using a variety of non-conventional drinking water treatment processes typically meant for point-of-use applications. Some of these non-conventional methods of treating water for consumptive purposes at the point of use are discussed in the following section.

2.2 Non-Conventional Drinking Water Treatment

As defined in the introductory section of this thesis, non-conventional drinking water treatment can often be used interchangeably with point-of-use (POU) drinking water treatment. Point-of-use treatment may include treating raw water sources at the point-of-consumption or it can be the further treatment of conventionally treated water in the home. Literature pertaining to point-of-use drinking water treatment technologies is relatively abundant and a review of all that is available is beyond the scope of this thesis. However, a brief overview of the main elements and findings regarding non-conventional drinking water treatment methods follows.

2.2.1 Simple Point-of-Use Water Treatment Processes

2.2.1.1 Heat Treatment

"Heat is the oldest, safest and most effective method of purifying water" (Health and Welfare Canada and Environment Canada, 1991). The boiling of water as a treatment method is well used throughout the world. This method works on the principal that the microorganisms present in the water supply cannot tolerate the high temperatures that are required to bring water to a boil. These high temperatures rupture bacteria cells and denature proteins so that the microorganisms die (AWWA, 1990). The amount of time that is recommended for boiling water so that water is safe for consumption varies widely in the literature as is illustrated in Table 2-1.

Based on this Table it is difficult to assess exactly how long that contaminated water should be boiled for to ensure disinfection as different agencies seem to have their own recommendation. In addition, with the exception of the USEPA, none of the papers cited defined what they meant by "boil" which leaves even further uncertainty. Rice and Johnson, microbiologists from the USEPA, state that the "suggested boiling times refer to

Table 2-1. Effective Boiling Times Cited in Literature

Reference	Boiling Instructions	Sufficient to:
Aukerman and Monzingo, 1989	Brought to a boil	Inactivate *Giardia*
Aukerman and Monzingo, 1989	55°C	Inactivate *Giardia*
Unknown (in Aukerman and Monzingo, 1989)	5 minutes at 64°C	Inactivate *Giardia*
Cerva, 1955 (in Aukerman and Monzingo, 1989)	Heated to 50°C	Inactivate *Giardia*
AWWA, 1994	Bring water to a rolling boil	Purify tap water
Dairy, Food and Environmental Sanitation Editors, 1993	Boil at 100°C for 1 minute	Kill any disease causing bacteria in the water
Fogel, 1982	Bring water to an instant boil	Kill *Giardia lamblia* cyst
Gabler *et al.*, 1988	15 minutes at 121°C	Kill bacterial spores
Tobin, 1984 (based on Geldreich and Cutrovo, USEPA and Environmental Health Directorate)	Boil for 1 minute	Kill almost all types of waterborne pathogens
Health and Welfare Canada, 1985b	Boil for 1 minute	Kill most pathogens
Health and Welfare Canada, 1985b	Boil for at least 5 minutes	Ensure disinfection
Health and Welfare Canada, 1986	Boil for several minutes (when in doubt, 5 minutes)	Kill protozoan cysts
Health and Welfare Canada, and Environment Canada, 1991	At least 15 minutes and one extra minute for every 300m above sea level.	Not stated
Health Canada Boil Water Notice, 1995	At least 10 minutes	Not stated
US Department of Health Education and Welfare, 1965	Vigorous boiling for 1 full minute.	Kill any disease causing bacteria in the water.
USDA Forestry Service, 1989	1 minute boiling 3-5 minutes at high altitude	Inactivate *Giardia*
USEPA (Rice, E. and Johnson, C. 1994 in AWWA, 1994)	Full boil for 1 minute. Full boil for 3 minutes to compensate for lower temperatures at higher altitudes.	Kill *cholera*
WHO, 1993	Vigorous rolling boil for around 1 minute.	Inactivate viruses, bacteria and *Giardia* cysts.

the total time that the water is held at a rolling boil and should not be confused with the first sign of bubbles being liberated in the heating process (AWWA, 1994)." Currently, Rice and Johnson are conducting an investigation requested by the Centers for Disease Control to try to resolve the issue of how long water should be boiled for to ensure adequate disinfection. The preliminary results of their study indicate that heating water to a full boil with a conservative safety factor of 1 minute is sufficient to kill cholera and 3 minutes adequately compensates for higher altitudes (AWWA, 1994).

Aside from the beneficial effects of inactivating microorganisms, boiling the water is also an effective way to remove volatile organic chemicals from conventionally treated drinking water (Gabler *et al.*, 1988). This results as the boiling points for volatile organics are generally much less than for water. Therefore, by heating the water, the volatile organics will reach their boiling points and enter the gaseous phase, thereby being removed from the water. USEPA researchers found that all of the volatile organic chemicals added to their test water were removed after 10 minutes at a rolling boil (Gabler *et al.*, 1988).

There are some limitations associated with boiling water that may deter people from using this method of water treatment on a regular basis. First, a source of fuel must be readily available to bring the water to boil. For living off the land expeditions this source of fuel may be wood to make a fire. But, building a fire takes time and energy and not every thirsty person may make the effort or have the "fuel" available to boil the water. Another limitation with boiling water is that the aesthetic quality of the water will not improve. Colour is not removed and often the taste is compromised (Gabler *et al.*, 1988). It should also be noted that the effectiveness of disinfection is reduced in turbid waters. This is because the organisms may become imbedded in particles, thereby protecting them from the heat or other forms of disinfectants. It is for this reason that it is recommended that the particles in the water "settle out" or are filtered prior to disinfection (Gabler *et al.*, 1988; Health and Welfare Canada, 1991a).

2.2.1.2 Chemical Addition

Chlorine

Under most conditions, chlorine compounds are suitable disinfectants of raw water. There are three chemically equivalent forms of chlorine that may be used as a disinfectant in drinking water treatment: (1) compressed gas, (2) solid calcium hypochlorite or, (3) a solution of sodium hypochlorite (AWWA, 1990).

When chlorine (Cl_2) is added to water (H_2O) the following reaction takes place: $Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^-$ (Montgomery, 1985). It is thought that hypochlorous acid (HOCl) is the agent responsible for the inactivation of bacteria and viruses by disrupting normal cell functions such as respiration and DNA activity (AWWA, 1990). However, compressed chlorine gas is typically not used in the purification of small quantities of water for individual use. Generally, small scale disinfection is carried out using either sodium hypochlorite solution (bleach) or solid calcium hypochlorite (AWWA, 1990).

The chlorine tablets commercially available in camping and department stores are solid calcium hypochlorite. There is a new type of tablet on the market that combines the processes of chlorination and flocculation and is called a "Chlor-Floc" tablet. Both types of tablets contain the necessary dosage for drinking water disinfection and should be used according to the instructions on the label.

Household bleach is a readily available form of chlorine. Regular household bleach contains 4 to 5¼% sodium hypochlorite. When bleach is added to water the following reactions ensue: $NaOCl \leftrightarrow Na^+ + OCl^-$ and $2H_2O \leftrightarrow H_3O^+ + OH^-$ so that $OCl^- + H_3O^+ \leftrightarrow HOCl + H_2O$. Once again the HOCl is thought to be the agent responsible for the inactivation of microorganisms but the disinfection efficiency is less with the hypochlorite ion form of chlorine than for the hypochlorous acid.

Once again there were some discrepancies in the literature regarding the effective dose of chlorine bleach in the disinfection of drinking water. For the most part, it was recommended that 2 drops (0.1 mL) of bleach be added per litre of water, mixed thoroughly by stirring or shaking, and allowed to stand for 30 minutes before consumption (WHO, 1993; Gabler *et al.*, 1988). If the water is turbid or if a slight chlorine odour is not detectable after this time, the treatment should be repeated or the initial dosage doubled (Health and Welfare Canada and Environment Canada, 1991; Tobin, 1987).

The disinfection effectiveness of recommended chlorine dosages and reaction time can be assessed with the help of CT values. A CT value is a measure of disinfection capability, where "C" is the residual disinfectant concentration in mg/L and "T" is the related contact time in minutes (USEPA, 1991). The USEPA has compiled several tables of CT values based on the evaluation of existing laboratory data on disinfection efficiency (USEPA, 1991). Adapted tables from this USEPA document of CT values for *Giardia* and virus inactivation have been included for both free chlorine disinfection (Table 2-2 and 2-3) and for chloramine disinfection (Table 2-4 and 2-5). By examining these tables it is evident that disinfection is compromised at lower temperatures as witnessed by the higher CT values at colder temperatures. Furthermore, for *Giardia* inactivation by free chlorine in Table 2-2, the higher the pH, the higher the CT value. Tables 2-4 and 2-5 list the CT values for chloramines. If ammonia is present in a water supply, as is the case in some of the water samples taken in the study area, then the disinfectant can be thought to have similar disinfection capabilities as in the chloramine tables. When discussing microbial inactivation by disinfection, "log removals" are more convenient to work with than "percentage removals." A 1 log reduction is equivalent to a 90% removal, a 2 log reduction is the same as a 99% removal and a three log inactivation is equal to a 99.9% inactivation and so on.

Table 2-1. CT Values for Inactivation of *Giardia* Cysts by Free Chlorine

Inactivation	0.5 °C			20°C		
	pH 7	pH 8	pH 9	pH 7	pH 8	pH 9
1.0 log	79	115	167	21	30	44
2.0 log	157	231	333	41	61	88
3.0 log	236	346	500	62	91	132

(adapted from USEPA, 1991)

Table 2-2. CT Values for Inactivation of Viruses by Free Chlorine

Inactivation	0.5°C		20°C	
	pH 6 to 9	pH 10	pH 6 to 9	pH 10
2.0 log	6	45	1	11
3.0 log	9	66	2	16
4.0 log	12	90	3	22

(adapted from USEPA, 1991)

Table 2-3. CT Values for Inactivation of *Giardia* by Chloramine

Inactivation	≤1°C	20°C
	pH 6 to 9	pH 6 to 9
1.0 log	1270	370
2.0 log	2535	735
3.0 log	3800	1100

(adapted from USEPA, 1991)

Table 2-4. CT Values for Inactivation of Viruses by Chloramine

Inactivation	≤1°C	20°C
2.0 log	1243	321
3.0 log	2063	534
4.0 log	2883	746

(adapted from USEPA, 1991)

To illustrate the applicability of these tables in the determination of appropriate reaction times for disinfecting a given volume of water with household bleach, several examples will be worked through. First, preliminary calculations of the chlorine concentration in regular household bleach was found to be 52500 mg/L. Therefore, when 0.1 mL of this concentration is added to 1L of water, the initial free chlorine concentration in the water sample is 5.25 mg/L. For the purpose of the following examples in Figure 2-1, it will be assumed that the desired residual chlorine concentration is to be 2.0 mg/L (i.e. the value for "C").

Example 1:	Target of 3 log reduction of *Giardia* Volume of water to be treated = 1 L Temperature of water = 0.5°C pH = 8 Ammonia is not present in the water.
Solution:	The CT value of 346 mg·min/L is obtained from Table 2-2. Therefore, (2.0 mg/L) · T = (346 mg·min/L) and T = (346 mg·min/L)/(2.0 mg/L) = 173 minutes. This is more than six times the recommended reaction time of 30 minutes as suggested in the literature.
Example 2:	Target of 3 log reduction of *Giardia* Volume of water to be treated = 1L Temperature of water = 20°C pH = 8 Ammonia is not present in the water.
Solution:	The CT value of 91 mg·min/L is obtained from Table 2-2. Therefore, (2.0 mg/L) · T = (91 mg·min/L) and T = (91 mg·min/L)/(2.0 mg/L) = 45.5 minutes. This is 15 minutes more than the 30 minute reaction time that is recommended in the literature for disinfecting water with bleach.
Example 3:	Target of 4 log reduction of viruses Volume of water to be treated = 1 L Temperature of the water = 20°C Ammonia is not present in the water.
Solution:	The CT value of 3 mg/L·min is obtained from Table 2-3 for pH of 6 to 9. Therefore, (2.0 mg/L) · T = (3 mg·min/L) and T = (3 mg·min/L)/(2.0 mg/L) = 1.5 minutes. This is far less than the reaction time of 30 minutes suggested in the literature.
Example 4:	Target of 4 log reduction of viruses Volume of water to be treated = 1 L Temperature of the water = 20°C Ammonia is present in the water.
Solution:	The CT value of 746 mg·min/L is obtained from Table 2-5. Therefore, (2.0 mg/L) · T = (746 mg·min/L) and T = (746 mg·min/L)/(2.0 mg/L) = 373 minutes. This reaction time is more than 6 hours.

Figure 2-1. CT Value Examples

From these examples it is evident that temperature, pH and the presence of ammonia are important considerations when determining appropriate reaction times for disinfecting water with chlorine. Lower temperatures, higher pH's, and the presence of ammonia will necessitate an increase in reaction time.

There are also other drawbacks to this method of purification. Many people find the taste and odour associated with the disinfection of water with chlorine unappealing. This chemical taste can be masked by adding flavoured drink crystals after the treatment time has elapsed. Another problem with the addition of chlorine to water is the formation of potentially carcinogenic disinfection-by-products. Organic matter in the water acts as precursors for these by-products of chlorination. An additional problem with this type of treatment is that chlorine loses its effectiveness with age and exposure to air, sunlight and heat (Health and Welfare Canada and Environment Canada, 1991). Nonetheless, if properly used, chlorine is an effective disinfectant.

Iodine

Iodine is another chemical that has proven to be an effective disinfectant over the years. Several forms of iodine can be used as a disinfectant including tincture of iodine, iodine tablets, and iodine crystals. Iodine tablets are readily available in camping and department stores and should be used according to the manufacturers directions. Iodine crystals, also available through camping stores are somewhat more complicated. Four to eight grams of crystals should be added to 30 mL of water in a glass bottle and shaken for one minute. After the crystals have settled, approximately 15 mL of this solution should be added per liter of untreated water. Since the iodine crystals are toxic, they should not be allowed to be transferred to the drinking container. The remaining crystals can be used in the same manner until they are no longer visible in the bottom of the glass bottle. For

optimum iodine disinfection, the bottle should be kept warm around body temperature (Health and Welfare Canada and Environment Canada, 1991).

A 2% tincture of iodine commonly found in medicine cabinets can be used to purify untreated water. Once again, various recommended contact times and disinfectant dosages were found in the literature. Health and Welfare Canada and Environment Canada (1991) say that 8 to 10 drops (0.4 to 0.5 mL) of a 2% tincture will purify 1 L of untreated water. Tobin (1984) and Gabler *et al.*, (1988) recommend approximately 5 drops (ca 0.25 mL) of a 2% tincture. Tobin adds that the solution should be well mixed and allowed to stand for 30 minutes.

Disinfection with iodine has some problems. First of all, effectiveness of iodine decreases with colder temperatures and turbid waters. Therefore, higher doses and longer contact times are recommended in these situations. Second, the taste of iodine is not particularly pleasant, but as with chlorine, this can be remediated with flavoured drink crystals. And finally, although iodine is an effective disinfectant for emergency and short term sources of drinking water, it is not recommended that iodine be used for more than three weeks per season. Furthermore, children, pregnant women and people with thyroid problems should avoid using iodine all together due to potential adverse health effects (Health and Welfare Canada and Environment Canada, 1991).

Although there were not any CT values found in the literature for iodine disinfection, it would be a reasonable assumption that higher concentrations and longer contact times would be necessary to ensure the inactivation of the cysts of *Giardia* and *Cryptosporidium* because these organisms are generally more resistant to disinfection.

2.2.1.3 Aeration

Another simple point-of-use treatment process is aeration. The USEPA identified simple and effective methods of removing volatile organics from drinking water using materials found in the common kitchen (Gabler *et al.*, 1988). The methods studied included boiling, electric mixing, pouring, open standing and various other forms of aeration. Electric mixing for ten minutes was effective at removing more than 95% of the volatile organics in the water. Other aeration techniques investigated including open standing of the water for at least 48 hours, pouring water back and forth between two containers twenty times and aeration of water using a device that aerates a fish tank. The open standing method was found to remove 95% to 98% of the chemicals, but this method has its limitations (Gabler *et al.*, 1988). Leaving the water stand for such a length of time will certainly foster bacterial proliferation. Also, waiting two to three days for a glass of water may not always be practical. The other aeration methods were not particularly effective.

Although the chemical disinfection methods and other simple processes just described may be appropriate for emergency situations or for short living-off-the-land excursions, there are other alternatives that may be more efficient for purifying drinking water on a continual basis. This may include the installation of a point-of-use device in the home. Such a system should employ as many processes as technically and financially possible. Depending on the source water quality, a multi-barrier approach will provide the highest quality water.

2.2.2 Point-of-Use Water Treatment Devices

The utilization of point-of-use treatment devices for supplying a safe supply of drinking water has been gaining popularity. "Point-of-use devices are treatment systems installed on single or multiple taps and are intended to treat water for drinking and cooking only (Health and Welfare Canada, 1991a)." According to the Canadian Water Quality

Association, the sale of point-of-use drinking water treatment devices is a 700 million dollar a year industry in Canada (Robertson, 1995). Currently there is no specific legislation in place governing point-of-use drinking water treatment devices (Robertson, 1995). Health Canada is working on the Drinking Water Safety Act which will include legislation for these devices.

Home treatment devices employ a variety of basic processes such as filtration, adsorption, ion exchange, reverse osmosis and disinfection. Different units are designed for different water quality problems. Some of the more sophisticated treatment units intended for individual homes are called package plants. These are essentially miniature conventional drinking water treatment plants that use a multi-barrier approach to water treatment. Generally, water treatment processes can be divided into those that disinfect by killing microorganisms and those that physically remove contaminants in the water supply. The different types of units available on the market are briefly discussed under these two headings.

2.2.2.1 Disinfection Units

"Disinfection is the one step in water treatment specifically designed to destroy pathogenic organisms and thereby prevent waterborne diseases, which are the most common health risks associated with drinking (Federal-Provincial Subcommittee on Drinking Water, 1993)." Some of the common disinfection methods used are the addition of oxidizing chemicals, applying heat and exposing the water supply to ultraviolet radiation.

Chlorinators

The use of chlorine with municipally treated water systems has virtually eliminated waterborne microbial diseases, due to chlorine's ability to kill or inactivate essentially all enteric pathogenic microorganisms (Health and Welfare Canada, 1991a). Water can be treated at the point-of-use with liquid sodium hypochlorite or solid calcium hypochlorite. As discussed above, hypochlorous acid generated from the addition of chlorine to water, inactivates bacteria and viruses by disrupting normal cell functions and DNA activity (AWWA, 1990).

Besides its effectiveness at inactivating microorganisms in the water, chlorine is also a suitable agent for the removal of iron and sulfur from well water (Health and Welfare Canada, 1991a). Therefore, when point-of-use chlorinators are used to remove iron and sulfur the consumers also have the added protection against microorganisms.

Ozonators

Ozone is an unstable form of oxygen that consists of three oxygen atoms (Jacobsen, 1994). Ozone has been called the most powerful disinfection agent known (Burris, 1986; Pontius, 1994). Researchers have hypothesized that there are two primary oxidation pathways when ozone is dissolved in water; direct oxidation by molecular ozone and indirect oxidation by free radicals that are formed during the decomposition of ozone in water (Zhou *et al.*, 1995). Typically, microbial inactivation occurs when ozone breaks molecular bonds on the cell well, thereby lysing the cell (Zhou, 1995).

For household applications, ozone is effective at eliminating taste and odour causing organics. Ozone is unstable and must be generated on site. Household type ozonators consist of a large box that has a hose emanating from it that bubbles ozone into a container of water (Tobin, 1987). These units require electricity and a large amount of

space to house the apparatus (Health and Welfare Canada, 1985b). Ozonation is dependent on good mixing of ozone with the water and has a very short lived residual disinfectant.

Ultraviolet Irradiation

Ultraviolet (UV) light is described as radiation with a wavelength between 180 nm to 400 nm (Gabler *et al.*, 1988). This is a shorter wavelength than visible light and therefore carries more energy (Gabler *et al.*, 1988). The mode of action in ultraviolet disinfection units is by the inactivation of the microorganism's DNA.

One type of home UV unit includes a mercury vapour lamp that emits UV light with a wavelength of 253.7 nm (Gabler *et al.*, 1988). This mercury vapour lamp is housed inside a cylindrical quartz sleeve and the water to be treated flows around the sleeve. UV disinfection has its disadvantages. First, turbidity in the water limits the effectiveness of UV disinfection (Culotta, 1989). Second, UV does not kill the spores of *Giardia* and *Cryptosporidium* (Jacobsen, 1994). Third, ultraviolet units require electricity and the equipment requires significant supervision and maintenance (Culotta, 1989).

Distillers

Distillation is a process whereby water is heated in a flask, and hot water vapor rises into a tube through a series of baffles into a collection chamber where the steam condenses and changes back to the liquid form (Gabler *et al.*, 1988). This type of treatment is effective at reducing dissolved solids, metals, minerals and particles because they remain in the boiling water (Culotta, 1989). Furthermore, boiling the water will effectively kill microorganisms. Distillers have their drawbacks. For example, if the untreated water contains chemicals with a lower boiling point than water (such as pesticides, chloroform, benzene, toluene and xylene), these chemicals will also boil off with water and become concentrated in the treated water (Lester and Lipsett, 1988).

2.2.2.2 Mechanical Particle Removal Units

Adsorption Units

Adsorption is the accumulation of a substance at the interface between two phases, such as a liquid and a solid (AWWA, 1990). Activated carbon is an effective adsorbent. Activated carbon can be made from a variety of substances including animal bone, coconut shells, wood or coal. The carbon is heated to extreme temperatures in the presence of steam and absence of oxygen so that minuscule pores within the material are formed, thereby increasing the surface area for adsorption and particulate entrapment (Geldreich and Reasoner, 1990). Activated carbon comes in three forms; Granular Activated Carbon (GAC), Powdered Activated Carbon (PAC) and a compressed activated carbon cake. Both granular and block carbon are preferred over the powdered kind because the powdered carbon is prone to releasing carbon particles into the cleaned water (Lester and Lipsett, 1988). The pressed carbon cake has an advantage over GAC because it avoids problems of channel formation that occurs with granular media (Geldreich and Reasoner, 1990).

Activated carbon units are effective at removing organic chemicals, taste and odour causing compounds and chemical compounds produced by microorganisms (Lester and Lipsett, 1988). But, they are not effective at removing heavy metals, nitrates, dissolved iron or bacteria. In fact, using activated carbon devices may lead to the deterioration of the microbiological quality of the treated water. Bacterial colonization of activated carbon point-of-use devices has been well documented (Gabler *et al.*, 1988; Geldreich *et al.*, 1985; Reasoner *et al.*, 1987; Regunathan and Beauman, 1987). Furthermore, once the carbon is exhausted, there is a potential for the collected contaminants (microbial and organic) to be sheared off and released from the filter beds leading to an increase in these contaminant levels in the finished water (Lester and Lipsett, 1988; Geldreich and Reasoner, 1990). It is for this reason that "Health and Welfare Canada insists that activated carbon filters and related packaging, promotional and instructional materials be

clearly labeled "Use only on municipally treated water or other supply known to be microbiologically safe" (Health and Welfare Canada, 1991b)"

Ion Exchange Units

Ion exchange is a process in which ions in solution are exchanged with ions of like charge located on the surface of the solid being contacted (Montgomery, 1985). Home water softeners work on the principal of ion exchange. They are primarily used to remove hardness from water, which in most natural water is made up of calcium and magnesium ions. Essentially, water containing calcium and magnesium ions is passed through a column filled with resin beads that have sodium ions attached to the internal and external surfaces. When the hard water passes these resin beads, magnesium and calcium ions are exchanged for sodium ions, so the magnesium and calcium is removed in the treated water (Geldreich and Reasoner, 1990).

Although the use of ion exchange units is widespread in the removal of hardness, ion exchange units are also effective at removing other types of contaminants as well. Cationic softeners exchange sodium and potassium ions for calcium, magnesium, iron and manganese ions. Anionic softeners exchange hydroxl ions for sulfates, nitrates, bicarbonates and chlorides (Culotta, 1989).

Reverse Osmosis Systems

Reverse Osmosis (RO) involves applying a pressure differential across a semi-permeable membrane so that dissolved ions, molecules and solids, cannot pass through, but water can (Geldreich and Reasoner, 1990). Rozelle (1987) explains that most RO systems placed at the point-of-use in a house utilize several processes in order to be most effective. First, the water passes through a particulate filter to remove larger particles. Second, the water

passes through an optional activated carbon filter. This filter is placed on-line for chlorinated water supplies to remove chlorine because many of the RO membranes are chlorine-sensitive. Third, water is forced through an RO module which is a water reservoir containing a pressurized rubber bladder. The most common types of semi-permeable membranes used in RO systems are cellulose acetate and polyamide (Rozelle, 1987). Finally, the water may pass through another optional activated carbon filter before it is delivered to the point of consumption. Although RO units are very effective at removing heavy metals, total dissolved solids, nitrates, asbestos and *Giardia* cysts, the membranes are not effective at removing small organic molecules. Also, the membrane must be properly cared for. It can be broken down by microbial degradation or excessive water pressure (Geldreich and Reasoner, 1990).

Filters

Filtration is a water treatment process used to remove suspended particulates such as clay, silt, microorganisms and other organics (AWWA, 1990). Removal efficiency depends on the quality of the water supply, as well as the type of filter material being used. There are many types of filter media such as spirally wound fibers, string, acrylic filaments, ceramic, sand, pleated paper, pleated non-woven fabric and membrane material with pre-determined pore sizes.

There are two classes of filters: depth filters and screen filters. Depth filters consist of an array of fibrous, granular or sintered material that is pressed, wound or bonded together and particles are trapped throughout the whole depth of the filter (Gabler *et al.*, 1988). In depth filters suspended particles are removed by any number of several processes including: (1) being strained through the pores in the filter bed; (2) adsorption of the particles to the filter grains; (3) settling of the particles while in media pores; (4) floc

growth while traveling through the pores; and (5) sometimes biological mechanisms (Jacobsen, 1994; Troyan and Hansen, 1989).

Screen filters retain all particles larger than its pore size on the upstream surface of the filter. An example of a simple screen type or membrane filter is a piece of cloth. Large particles in the water are removed when water is strained through a piece of clean cloth. The size of the mesh is the controlling factor in this method and the smaller the weave, the better. There are also membrane filter papers available that have a pore size of 0.2 microns. With this small pore size, these filter papers are capable of retaining all bacteria (Gabler *et al.*, 1988). Due to the small particle retention surface of these screen type filters, they clog rapidly. Furthermore, they are expensive (Gabler *et al.*, 1988).

Currently there are a wide variety of portable point-of-use drinking water treatment filters that claim to be suitable for treating contaminated drinking water for wilderness camping and international travelling purposes. Both depth and screen type filters are used in these portable units. A variety of media has been used in the units and several different designs are available. A thorough assessment of the portable drinking water treatment units in Edmonton and surrounding area resulted in the compilation of the different types of devices on the market. The findings are presented in tabular format in Section 5.

Without an in-depth analysis of all homes in the Northern River Basins Study area it is difficult to assess which types of point-of-use units and processes are being utilized in the study area. It is likely that many of the people living in remote rural areas may be using some of these types of systems. And it is also possible that many of the people that receive their drinking water from a conventional treatment facility further treat their water with a point-of-use device before they drink it.

2.3 Non-Conventional Sources of Drinking Water in Canada

It was found that literature strictly pertaining to the utilization and quality of non-conventional drinking water in Canada is limited. However, some of the literature encountered did make reference to the consumption of non-conventional sources of drinking water in Canada.

2.3.1 Health and Welfare Canada, 1973

Sanitation Manual for Isolated Regions (Health and Welfare Canada, 1973) is essentially a sanitation reference guide for people living in remote northern areas. The manual contains two sections on drinking water describing the fundamentals of water quality and water treatment. Although this document does not specifically deal with non-conventional sources of drinking water, an appendix in this document discusses how many people living in remote northern locations utilize ice from nearby lakes or rivers as a source of drinking water. The Appendix describes how ice is sawn into blocks, hauled out of the water and is stacked near the house or stored in an ice house so that it can be used in the summer. The authors state that "in most cases the water is relatively free of bacterial contamination when it is in the river or lake, but usually it becomes contaminated by the workman and dogs during handling." It should be noted that this document was published over twenty years ago, so it may not necessarily reflect the method of ice collection and ice water quality at the present time. However, the importance of treating the ice water to remove potential contaminants is explained and three methods of treatment are mentioned. First, the ice block should always be washed with water to remove the outer layer of the ice block. It is particularly important to break apart melded blocks before washing because bacteria can become trapped between them. Second, chlorine can be used to disinfect the melted water. Third, boiling is also mentioned as an effective method of destroying pathogenic microorganisms.

2.3.2 Brocklehurst, Heinke and Hodes, 1985

The goal of this study was to establish a relationship between the level of community service and the level of public health on thirteen Indian reserves in Manitoba. The level of public health on the reserves was established utilizing health record data for selected water related diseases. Municipal service data for each community was collected through site visits and by surveying residents regarding water supply, sanitation, satisfaction and the perceived health impact that these services have on health.

A "servicing scoring system" was devised as a means of assigning a numerical value to the level of municipal service in a community. A score between one and ten was assigned for each type of water supply system (as in Table 2-6) and then a community was assigned a "total score" by multiplying the percent of the community using the system with the score that system was assigned.

Table 2-6. Municipal Servicing Scoring System

Water Supply System	Score
Piped water	10
Well connected to household plumbing	9
Trucked delivery to cisterns (2300L to 4600L)	8
Trucked delivery to sealed small tanks	5
Trucked delivery to small tanks, pails or barrels (<900L)	4
Self haul from well	4
Self haul from nursing station, treatment plant or school	4
Self haul from standpipe	4
Self haul from lake	1

Although the term "non-conventional" source of drinking water is not utilized by Brocklehurst *et al.*, (1985), for all intents and purposes, all of the "self hauled" sources as well as the "well connected to household plumbing" could be defined as a non-conventional source of drinking water. There is no description regarding the development of this scoring system in the paper, so it is not known how the scores were assigned to each water supply system. However, Brocklehurst *et al.*, (1985) state that the

"correlation between score and water consumptions is almost linear, except at the upper and lower ends of the scale. Lake water hauling, while providing water volume comparable to standpipe self haul, receives a lower score, and wells and cisterns connected to household plumbing, while providing water volumes similar to piped systems, score lower due to lower reliability." It is interesting to note that all of the self hauling systems are assigned a relatively low servicing score with lake water being the worst.

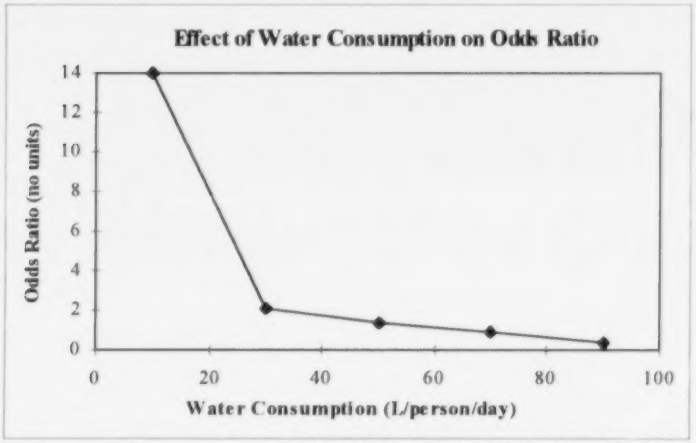
One of the main findings of this study by Brocklehurst *et al.*, (1985) was that municipal services on many of the reserves studied were inadequate and low servicing levels were related to poor health. Health data indicate that a minimum of 90 L of water per person per day is required It was found that an overall "score" of approximately 6.5 is necessary to reduce hospitalization rates on the reserves to near the provincial average. Although there are no water supply systems with this "score", it does indicate that "any trucked delivery system to small barrels, tanks or pails is insufficient in terms of health, and does not provide a sufficient quantity of water." Only three of the thirteen Indian reserves studied had a total score greater than six. Although the authors acknowledge that piped water is not an economically viable alternative for many scattered communities, systems that provide full indoor plumbing (shower, bath, flush toilet, hot water on demand) supported by trucked delivery or a well, are required to provide an acceptable level of health.

2.3.3 Robinson and Heinke, 1990

This study was undertaken to determine the relationships between municipal services and public health in two communities in the Northwest Territories. Research was carried out as a matched *case-control* epidemiological study in which *cases* were individuals with a reported incident of diarrhea, and *controls* were individuals with a reported respiratory tract infection. The health related information was gathered from a central database in Yellowknife. The municipal service data was collected in the communities and included the quantity of municipal water used, type of sewage disposal and cleanliness of the

residence. Once all of the information was collected, the data was organized into a series of matched two by two case-control tables to establish the relevant odds ratios in order to determine statistical significance. Although there have been many epidemiological studies like this one done in the developing world, apparently this was the first one of this nature to take place in a cold weather climate.

It was found that neither the type of sewage disposal nor the cleanliness of the residence related well to the occurrence of diarrhea. However, there was a significant increase in the risk of diarrhea associated with low water consumption. These conclusions were reached based on calculated odds ratios. An odds ratio greater than one suggests a strong correlation between the cases (diarrhea) and the exposure variable (quantity of water consumed). An odds ratio less than or equal to one suggested no additional risk of diarrhea due to the exposure variable. Figure 2-2 shows that there is a significantly higher risk of diarrhea for water consumption rates of less than 20 L/person/day. At 30L/person/day the risk has decreased substantially from an odds ratio of 14 to an odds ratio around 2. An odds ratio of one is correlated with a consumption rate of approximately 65 L/person/day at which point there is no statistically significant additional risk of acquiring diarrhea.



(adapted from Robinson and Heinke, 1990)

Figure 2-2. Effect of Drinking Water Consumption on Odds Ratio.

The reason that the findings of this report is included in the literature review section of here is because the authors have hypothesized two reasons why low water use results in a higher incidence of diarrhea.

> "The first hypothesis is that the cases are actually using very little water, and pathogens suspected of causing diarrhea are being passed and ingested because of insufficient washing of hands, utensils, food, clothes, etc. Since there was sufficient water available in the study communities, and there is no additional cost associated with additional water use, this hypothesis suggests that greater public health education is required to reduce incidence of diarrhea. The second hypothesis is that those using little municipal water are acquiring water from other, untested sources, and it is from this unsanctioned water that pathogens suspected of causing diarrhea are obtained. It is the suspected avoidance of chlorinated water supplies which ultimately causes the diarrhea. This second hypothesis carries implications about the value and quality of chlorination of water supplies in Inuit communities. While it has previously been understood that chlorination was 'good' for Inuit communities, these findings indicate that it may be 'bad'."

Although this report is not specifically a drinking water study, this second hypothesis is certainly inferring a strong drinking water component; particularly the effect that "unsanctioned" or non-conventional drinking water may have on a person's health which in this case is diarrhea. There are other acknowledgements of this non-conventional sources of water in this report. The authors reported knowing a number of people in the study communities that hauled their own water and stated that the use of alternate sources of water "is common in Inuit communities." Therefore, the utilization of non-conventional sources of drinking water in the study subjects could be a confounding variable in the results obtained. Robinson and Heinke acknowledge this but state that they do not believe that there is any significant difference (i.e. housing, plumbing, water use) within this group of people that utilize alternate, non-conventional sources of water for drinking. Nonetheless, further research into this area is necessary but the relevant data collection would require an in depth and time consuming survey of residents.

2.3.4 Health and Welfare Canada and Environment Canada, 1991

The pamphlet "Wilderness Water: A Guide to Wilderness Drinking Water" is targetted to wilderness campers. It discusses four important areas with relevance to non-conventional drinking water supplies. The first is "Where should Drinking Water Be Obtained?". Essentially it is recommended by the authors that for short trips "water from home or another safe source" should be used. However, this pamphlet mentions that "well water, fast moving rivers and the deepest parts of lakes are the best locations to obtain water." In addition, it is stated that stagnant water, shoreline water and water close to human habitation should be avoided. During the winter it is recommended to obtain water through an open hole in the ice rather than melting snow or ice because the later process is fuel and time consuming.

The second and largest section of the pamphlet is "Water Purification Methods" which has been further divided into a section on each of boiling, chemical purification and filtration. Under Boiling, it says that "heat is the oldest, safest and most effective method of purifying water." The authors state that water should be boiled for at least 15 minutes and one additional minute should be added for each 300 m above sea level. The flat taste of boiled water can be remedied by letting the water cool or by pouring the water back and forth between containers. According to this pamphlet, the chemical purification of water can be obtained by using chlorine or iodine compounds. Two drops of household bleach is sufficient to disinfect 1 L of water after a 30 minute contact time. Eight to ten drops of 2% tincture of iodine should be enough to purify 1 L of water. However, chemical age, water quality, temperature all influence these chemical reactions and sometimes more chemical or a longer contact time may be necessary. The final purification method discussed in the pamphlet is filtration. The variety of filters available on the market is mentioned and it is highlighted that care should be taken when choosing such a device. For example, it states that filters that allow particles larger than 0.5 microns to pass should be avoided. In addition, charcoal based filtration devices are not recommended. "Passage through an activated carbon filter alone does not disinfect water effectively (and) devices

that operate only with activated carbon should not be used." Whatever the filter, operating and maintenance instructions should be carefully followed.

The third topic covered in the pamphlet is the importance of "Keep(ing) the Environment Healthy". The importance of using biodegradable soap, and properly disposing of wastewater and solid waste in the wilderness is discussed. Following these guidelines will help protect the wilderness water supply for generations to come.

The final word regarding wilderness water in this pamphlet regards health. It states that some waterborne diseases are difficult to diagnose and if you get sick after consuming wilderness water, "inform your doctor that you have consumed untreated water."

2.3.5 Other Sources of Information

There has been a large amount of work undertaken in developing or tropical countries relating water supply and sanitation to health. In many of these studies diarrheal morbidity or mortality is used as an indicator of health. Esrey, Feachem and Hughs (1985) analyzed 67 studies on the impact that water supply and sanitation have on various health related parameters. They concluded that diarrheal morbidity rates could be reduced by 35% to 50% with well designed projects that incorporate water supply, sanitation and hygiene education. They also noted that there is a general deficiency in the knowledge regarding the impact that water supply and sanitation have on diarrheal disease. Although the studies analyzed were from developing countries, it can be assumed that the same may be applied to some areas in Canada, particularly isolated remote locations with poor water supply and sanitation facilities.

A case-control epidemiological study in Brazil by Victoria *et al.*, (1988) examined the effect of water and sanitation facilities on infant mortality due to diarrhea. It was found that homes with piped water had an 80% lower infant mortality rate than homes without

easy access to piped water. "These findings suggest that the beneficial effects of piped water may relate to the easy availability of water rather that to its quality." One would have to consider that this could also be the case in remote areas in Canada as well. However, it should also be noted that Canada as a whole is more affluent than Brazil and many of the remote isolated homes in Canada have access to large quantities of water by other means such as from a nearby well, a dugout, or water hauled to cisterns and barrels by a water truck. Nonetheless, there are certainly some homes in Canada that have the burden of hauling water in small containers.

Another main source of information was through contact with various people that were knowledgeable in the assessment of non-conventional drinking water and related areas. Numerous government agencies were contacted including several people from Health Canada, Alberta Environment, Alberta Health and several Aboriginal organizations including the Assembly of First Nations and the Department of Indian and Northern Affairs. It was from talking to people from these agencies that it was determined that there was a very limited body of literature pertaining to the assessment of non-conventional sources of drinking water in Canada. Several local businesses were contacted in regards to the point-of-use water treatment industry. Although there seemed to be a wealth of information about many of the devices, the information on portable point-of-use drinking water treatment filters was more difficult to come by.

2.4 Non-Conventional Sources of Drinking Water in the Study Area

2.4.1 Fort MacKay Indian Band and Fort Chipewyan Cree and Chipewyan Indian Bands, 1988

The Northern Athabasca River Basin Study was initiated and carried out by Chipewyan and Cree Indian Bands living in the Athabasca River Basin. The purpose of this study was to determine the impact that development has had on the Athabasca River. From this

study it was concluded that "water quality degradation has imposed great changes on the use of the river for domestic, especially drinking water use and for fishing ." The water quality degradation perceived by those interviewed in the study was deemed to be a result of oil sands operations, sewage effluents, and general upstream pollution. Therefore, in this report reference is made to using the river for drinking water purposes which could essentially be considered a source of non-conventional drinking water in this report.

2.4.2 Traditional Knowledge Component, 1995

The Traditional Knowledge Component of the Northern River Basins Study collected information through in-person interviews of 221 people from nine different native communities in the Northern River Basins. There was a qualifying criterion for respondents of the questionnaire in that they had to have lived a traditional lifestyle at some point in their lives. It is because of this criterion that the average age of respondents was 58 years old which is higher than for the northern adult population as a whole. Therefore, in the interpretation of the results of the Traditional Knowledge Component presented here, it is important to keep this selection criteria in mind and that the results may not necessarily reflect all segments of the population in the NRBS area.

The overall average rating of nearby water quality by NRBS Traditional Knowledge Survey respondents was seen as somewhat negative. The average water quality rating based on a five point scale (with one being the worst and five being the best) was 2.6. Figure 2-3 shows the percent of responses for perceived water quality changes observed by Traditional Knowledge Survey respondents. More than three-quarters of respondents indicated that they had noticed a change in algae growth and approximately half of those interviewed noted a change in the water insect population and turbidity.

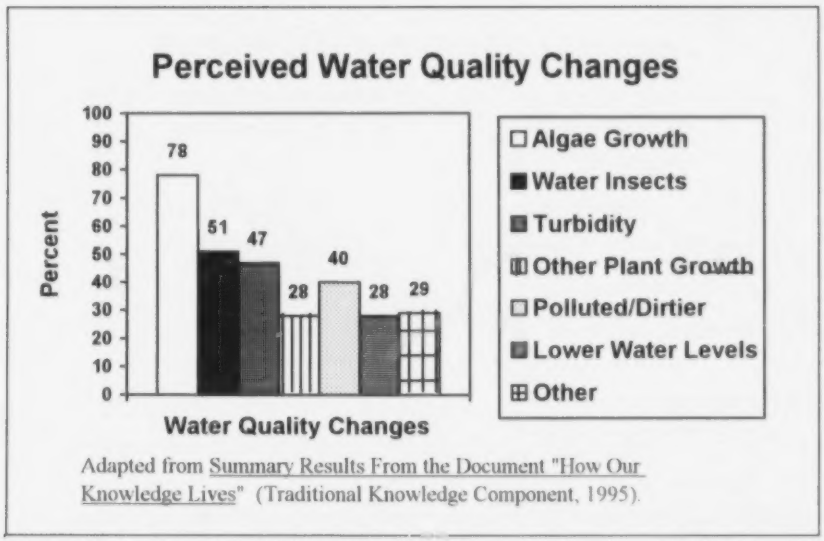


Figure 2-3. Perceived Water Quality Changes Based on NRBS Traditional Knowledge Interviews

The Traditional Knowledge Survey also asked whether or not respondents felt that water quality had affected their health or the health of others. Fifty-two percent said that their own health had been affected, 42% indicated that their spouses health had been affected, 37% reported an affect on their children's health and 58% checked off other people's health (Traditional Knowledge, 1995). Thirty six percent of respondents did not know whether their health or anyone else's health had been affected by water quality.

A large percentage of people interviewed in the NRBS Traditional Knowledge Survey, utilize lake and river water for consumptive purposes. Apparently, there are also many people that have changed their practices of using lake and river water. When asked why they stopped using lake or river water, the various reasons cited were bad taste (41%), bad smell (31%), colour (39%), disease (49%), and other reasons (28%). From this, it is evident that approximately half of the respondents that no longer use lake or river water associate some form of disease or ill-health with consuming it. The reasons stated for what made them stop were self experience (55%), media (23%), health warnings (44%), public education (21%) and other reasons (31%).

As was found by the Traditional Knowledge Component Survey (1995), there are many people of native descent that live off of the land year round (66% of those interviewed), for most of the year (18%), for half of the year (8%), and seasonally (8%). For these people, their water is typically obtained from natural water sources in the wilderness. Therefore, people that live off the land are among those that utilize a non-conventional source of drinking water. Another finding of the Traditional Knowledge Component Survey was the source of water for daily use by those interviewed. Figure 2-4 shows that 63% of respondents utilize surface water, such as from lakes or rivers, for daily use. Twenty-six percent of those interviewed use various sources of water for daily use and only 5% obtain their water from a water treatment facility. Although this low number of people obtaining water from a treatment plant is alarming, it must be considered that the people interviewed in the Traditional Knowledge Survey are typically elders and second-generation elders and from above, it appears that many of those interviewed live off of the land. However, it is also suspected that many people in the NRBS area that do have access to conventionally treated water, particularly elders, may choose an alternate source of water when given the choice between conventionally treated water and some other source of water.

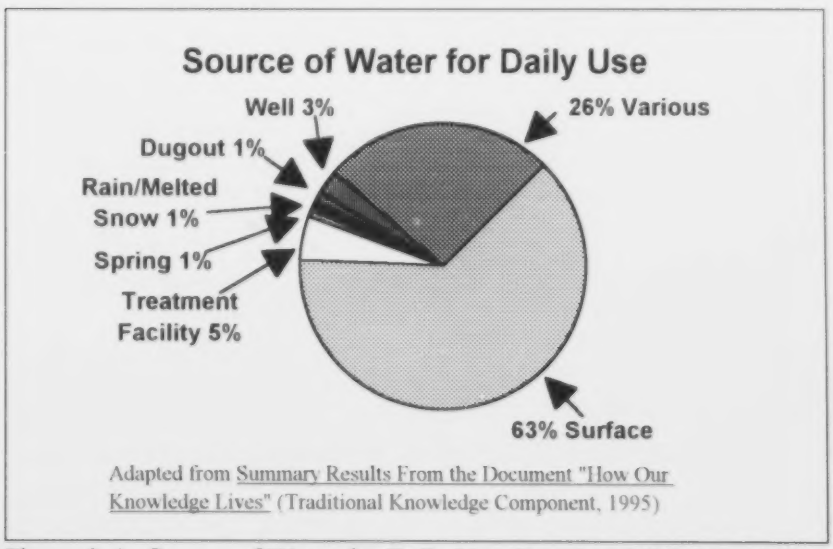

Source of Water for Daily Use
Well 3%
26% Various
Dugout 1%
Rain/Melted Snow 1%
Spring 1%
Treatment Facility 5%
63% Surface
Adapted from Summary Results From the Document "How Our Knowledge Lives" (Traditional Knowledge Component, 1995)

Figure 2-4. Source of Water for Daily Use Based on NRBS Traditional Knowledge Interviews.

This report is probably the most significant work of all the literature encountered of particular relevance to this thesis. First, the results obtained are from residents of the Northern River Basins Study area which is also the study area for this thesis. Second, it gives some idea of the scale of non-conventional drinking water utilization among residents of the NRBS area. However, there are certainly some factors that must be considered in the interpretation of these results. First, these figures do not necessarily reflect the practices of all residents of the NRBS area. This is because the sampled population was carefully selected with the criterion of having to have lived off the land. This would preclude many of the younger people and hence does not reflect the larger population as a whole. Second, the ethnicity of those interviewed were all of native descent so this must also be considered since there are many non-native people living in Northern Alberta as well. Nonetheless, the results obtained from the Traditional Knowledge Component provide some invaluable information.

2.4.3 Prairie Farm Rehabilitation Administration, 1995

The Prairie Farm Rehabilitation Administration (PFRA) has a Rural Water Supply Program in place to financially and physically assist farmers in building dugouts and groundwater wells (Gibbens, 1995). PFRA's data was compiled for both dugouts and ground water wells in the Northern River Basins Study area. For dugouts, it was found that there were 5000 dugouts that are being used as a source of domestic water. This means that the dugouts provide water for all of the water needs of the home it supplies. Theoretically, this definition would include water necessary for the drinking water supply of the house. Figure 2-5 shows the location of these dugouts.

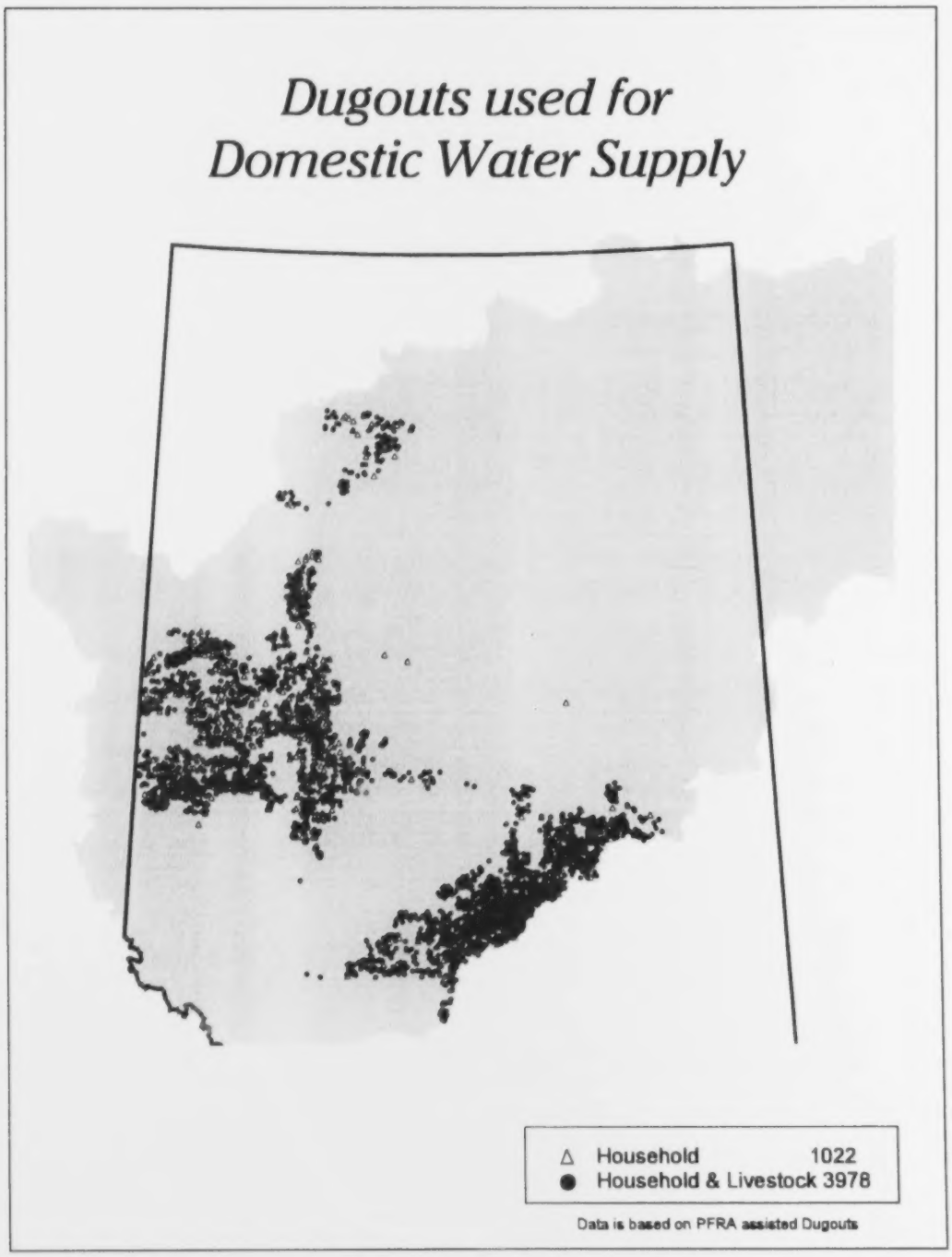


Figure 2-5. Dugouts Used for Domestic Water Supply in the NRBS Area.

It should be noted that the dugouts in the figure are only those in which PFRA has been involved. It is possible that there are other dugouts in the Northern River Basins Study area that were built without the assistance of PFRA and therefore, these dugouts were not included on this map. Also, there are some dugouts in the area that have not been categorized by type of use. It is possible that some of these dugouts are also used as a source of drinking water. In any case, the numbers on the map suggest that many of the people not receiving their water from a conventional drinking water treatment plant, may be obtaining their drinking water from individual dugouts.

The type of treatment that is being used by these households is not available on PFRA's databases and the only way to find this information would be to survey all dugout owners which was beyond the scope of this study. The level of treatment will depend on the intended use of the dugout water. The water quality of dugouts is not officially monitored by Alberta Environmental Protection or any other agency. It is considered the responsibility of the owner to maintain the dugout and perform any necessary treatment and monitoring.

Figure 2-6 is a map of the location of PFRA assisted groundwater wells in the NRBS area that are known to be used as a source of domestic water. As stated above, domestic means that this is the water that is used to fulfill the water requirements of the home it supplies which implies that it is also used for consumptive purposes (Gibbens, 1995). According to Figure 2-6, there are 3409 wells that fit this description. Once again, it should be noted that the wells on this figure are wells that were drilled with the assistance of PFRA's Rural Water Supply Program. David Gibbens from PFRA said that there are likely many more wells in the NRBS area that have been drilled by other agencies. This is particularly true for non-farming communities because it used to be the case that in order to qualify for a grant, the applicant would have to be a "bonafide farmer" (Gibbens, 1995). This is changing though because PFRA has changed its mandate somewhat to include the needs of all rural residents, not just farmers.

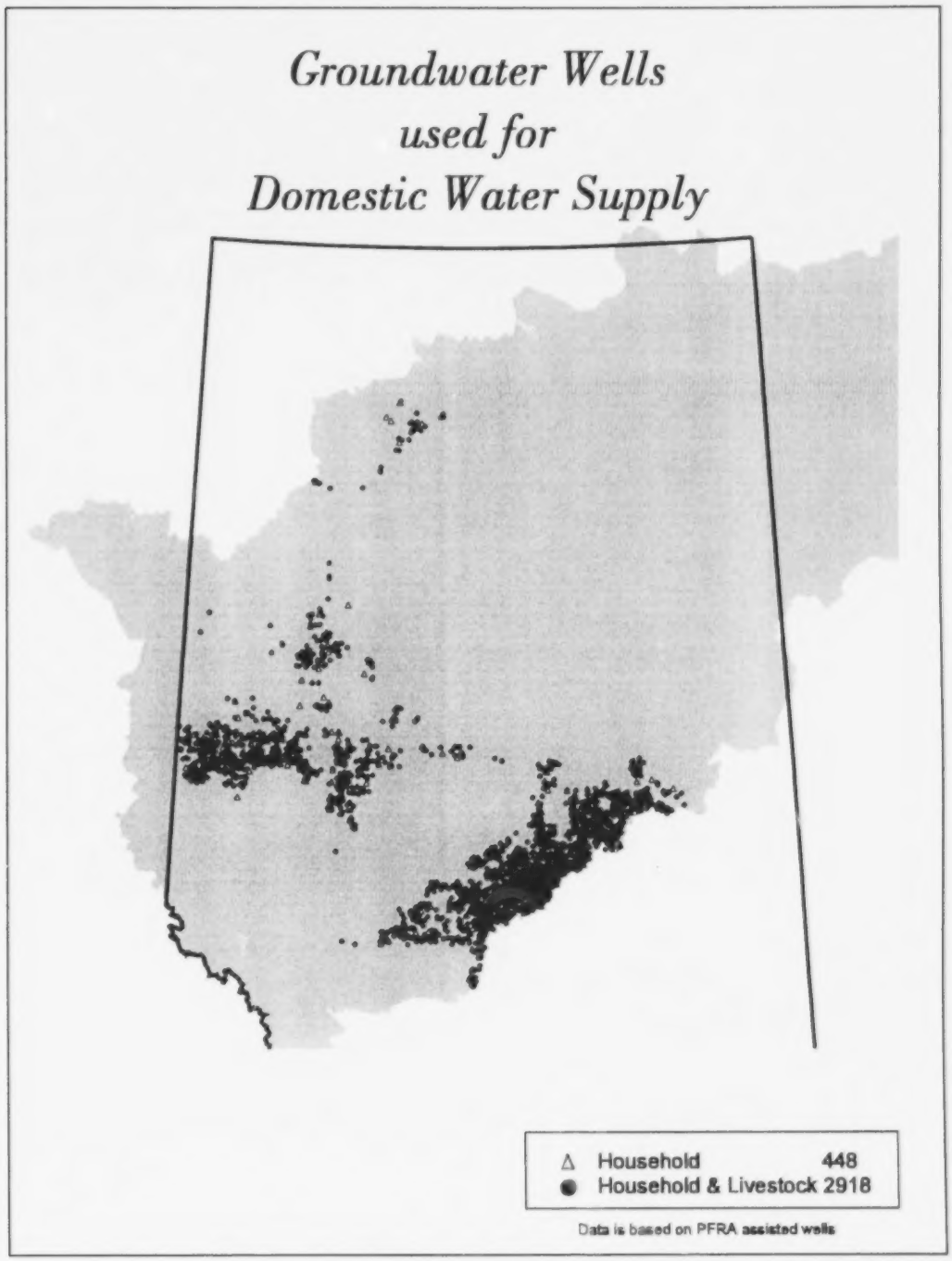


Figure 2-6. Groundwater Wells Used for Domestic Water Supply in the NRBS Area.

2.4.4 Other Sources of Information

People working in government agencies were contacted with regards to the monitoring of drinking water quality in the NRBS area. It was found that the federal department of Health Canada is responsible for monitoring the quality of drinking water on Indian and Inuit reserves, in National Parks and in federally owned buildings and properties. The rest of the drinking water in the Northern River Basins Study area is monitored by Alberta Environmental Protection. As a result of contacting people in each of these branches, and based on available information, historical water quality data on some of the non-conventional sources of drinking water in the NRBS area such as water from snow and ice is not available. However, there has been one related study done by Alberta Environmental Protection in the Peace-Athabasca Delta called the Drinking Water Survey in which samples were taken at various remote locations where people claim to be using the water for consumptive purposes (Flett, 1994). Although the sampling portion of that program is over, the data has not yet been compiled (Jackson, 1995).

In the spring and summer of 1995, the Other Uses Component of the Northern River Basins Study was involved in a telephone survey of a large random sample of NRBS residents. The survey instrument used by the Other Uses group included questions regarding the source of drinking water consumed, types of household water treatment utilized, as well as questions about water quality and quantity. Once compiled, the results of this survey will provide excellent baseline information regarding the consumption of non-conventional sources of drinking water in the study area.

The main source of information in the assessment of non-conventional drinking water in Northern Alberta was obtained from personal interviews with residents of the Northern River Basins themselves. The findings from these interviews and the results from the analysis of non-conventional drinking water samples are presented in Section 4.1 and 4.2.

3. FIELD STUDY METHODOLOGY

3.1 Field Trip Preparation

3.1.1 Site Selection

Field work was deemed to be an essential component to this research from the onset of the study. Research sites in the study area were chosen based on the following criteria:

a) The knowledge of the utilization of some type of non-conventional drinking water. To a large extent this criterion was fulfilled based on the recommendations of Northern Alberta residents, NRBS Traditional Knowledge leaders and government health officials who were familiar with the communities in question.
b) The willingness of the community to accept drinking water researchers into the area to take non-conventional drinking water samples and to talk to residents.
c) The availability of a suitable guide from the community who would not only act as a guide during the course of the research, but who could also act as a liaison between community members and researchers. In all three places this task involved some language translation.
d) The accessibility of the community in question.
e) The geographical location was considered because it was desirable to have samples from different locations in the study area rather than a cluster of samples from one geographical area.
f) The size of the community was also a factor to a lesser extent. Smaller communities were preferred because they were often more remote and as a result may have had a higher usage of non-conventional drinking water.

All of these criteria were met for the three study sites chosen which are shown on the map in Figure 3-1. The first of these was in the Fort Chipewyan area which is the central meeting place of all three river basins. Research in this area was conducted from September 26, 1994 to September 29, 1994. Secondly, from October 31, 1994 to November 4, 1994 communities near High Level, John D'Or Prairie and Fox Lake were visited, people were interviewed and samples were taken. On February 28, 1995, water samples were collected from Atikameg which is located north of Lesser Slave Lake in the Peace River Basin. Since the three sites chosen for research were all located within or near Treaty 8 Indian Reservations, the local Chief or Band Leader was consulted to ensure that it was all right to do non-conventional drinking water research in their communities. This was done in accordance with set protocols established between the Northern River Basin Study and Treaty 8 communities.

3.1.2 Obtaining a Community Guide

One of the most important aspects of the interviewing and sampling component of this thesis was the support and knowledge of a resident of the community visited that acted as a guide during the field trips. The selection and cooperation of a good community guide was of paramount importance to the success of the field work. Guide selection was completed prior to visiting the communities and was based on the recommendations of others. For the Fort Chipewyan trip, Fred Fraser was recommended as a knowledgeable guide who also owned a boat so that we could reach some of the more remote locations in the area. The second field trip up into the High Level, John D'Or Prairie and Fox Lake area was somewhat different because it was planned in conjunction with some work being conducted by the Traditional Knowledge Component in the same area at the same time.

Figure 3-1. Sites Visited in Assessing Non-Conventional Drinking Water in Northern Alberta

The primary guide and interpreter in this instance was Lea Bill, although a guide from each community was hired upon arrival. In John D'Or Prairie, Lester St. Arnault assisted in the field work and in Fox Lake this task was undertaken by Lesley Laboucan. There are also several non-native communities in the High Level area. Therefore, prior to this trip, the Regional Environmental Health Officer, was contacted for his input regarding non-conventional drinking water in the non-native areas up there. As it turned out, he also acted as a community guide for a day in the areas around High Level, Fort Vermilion and La Crete. Water sampling records were also available for perusal at the Health Center in High Level. The guide for the third and final field trip was obtained through Health Canada contacts. The location of the third field trip was chosen to be somewhere in the central part of the Northern River Basin Study area because sites in the north east (Fort Chipewyan), north west (High Level), and north central had already been visited. A community was found in which a Community Health Representative (CHR) would be available to act as a guide for a day. The community was Atikameg and the guide was Rosie Chalifoux.

3.1.3 Arrangement of Dates for Field Work.

The recommended guides were contacted in each community to discuss the objectives of the field research and to ask them if they would be willing to take on a job as a guide for the project. If they agreed, then a suitable time to come into their community to do the work was arranged. After the dates were decided, other travel arrangements could then be made such as transportation and hotel reservations. A few days prior to visiting the communities, the guides were contacted again to confirm coming into the area and to arrange a prospective meeting time and place upon arrival.

3.1.4 Preparation of Interview Questions

For the first field trip up to Fort Chipewyan, a list of questions for interviewing purposes had been prepared regarding non-conventional drinking water utilization and treatment, drinking water quality perception and health related questions as in Figure 3-2.

These questions were essentially memorized prior to going into the communities for ease of questioning the interviewees in the field. Although these questions were not asked word for word for reasons explained later, the general topics of source of non-conventional drinking water, treatment applied and perceived health effects were covered in the interview sessions.

3.1.5 Selection of Sample Parameters

The samples to be collected were analyzed for several physical, chemical and microbiological parameters. Some of this analysis was to be done in the field at the site of collection and some of the tests were sent to a laboratory for further analysis.

Most of the physical and chemical parameters that were analyzed in the field are routine parameters that give a general description of the composite water sample and those that affect the aesthetic appeal of the water for drinking. The work carried out by Prince *et al.*, (1995) was consulted in deciding which physical and chemical parameters to analyze for. The parameters that were tested in the field were turbidity, temperature, pH, conductivity, free and total chlorine (if applicable), ammonia, odour and colour. Turbidity was measured with a portable Hach turbidimeter that was calibrated with prepared formazin suspensions. A pH meter was used for the pH measurements and the rest of the field analyses were performed with a portable Hach Drel/5 Spectrophotometer.

GENERAL INFORMATION

Name:

Location(on map, schematic)

~Age:

DRINKING WATER QUALITY RELATED

RAW

1. Where do you get your drinking water from?
2. Where do you get your drinking water from when you are living off the land?
3. Have you noticed any changes in this water over time?

TREATED

4. Do you do anything to this water before you drink it?
5. Have you always done this?

If Boil

a) What method do you use to boil the water? (Fuel, gas, wood)
b) How long do you boil for?
c) How much water do you boil at a time?
d) Where do you store the water that you don't use?

If Halogenate

e) What disinfectant do you use? (Chlorine, Iodine..)
f) What form? (tablet, liquid, powder)
g) Where do you get it from?
h) How much water do you use with the disinfectant(Dose)?

If Filtration

i) What kind of filter do you use?
j) How much water does it filter?
k) Do you do anything else to it?

STORAGE/DISTRIBUTION

6. Where do you store the excess water?
7. How long do you keep it there before you fill it up again?

OTHER USES

8. Where do you obtain your water for washing dishes? brushing your teeth? cooking?

HEALTH EFFECTS

9. Have you or anyone you know been sick as a result of your drinking water?
10. What were the symptoms? nausea? cramping? diarrhea?
11. How long did it last?
12. Did you visit a health facility? Did they give you any medication? What kind?

Figure 3-2. Non-Conventional Drinking Water Interview Questions

The metals selected for analysis were chosen based on all of the heavy metals that are regulated in the Guidelines for Canadian Drinking Water Quality either for health reasons or aesthetic reasons. This included Boron (B), Arsenic (As), Barium (Ba), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Manganese (Mn), Lead (Pb), Mercury (Hg), and Zinc (Zn).

A wide variety of microorganisms were chosen for analysis to try to get a more representative profile of the microbial population of the water sample. The microbiological enumerations that were performed by the membrane filtration technique were: total coliforms (TC), fecal coliforms (FC), heterotrophic plate counts (HPC), fecal streptococci (FS), *Klebsiella*, Yeasts and Molds. Total coliforms and fecal coliforms are regulated in the GCDWQ, and therefore any drinking water study would be negligent if these two microbial indicators were not assayed. The Fecal Streptococci group of bacteria are comprised of species from the *Streptococcus* genera that possess the Lancefield group D antigen (WHO, 1993). Fecal streptococci are more numerous than coliforms in the feces of farm animals, cats, dogs and rodents. *Klebsiella* was chosen because these organisms have been associated with pulp mill wastes (Emde, 1995). Therefore, due to the relatively large number of pulp mills in study area, the enumeration of these microorganisms may provide insight into the effects that some of these mills may have on the water systems. Yeasts and molds are types of fungi that are found in the aquatic environment. Yeasts and molds in a water supply are associated with taste and odour problems in drinking water and were therefore also included in the analysis (Emde, 1995). In addition, due to the thick cell wall of yeasts, these organisms have been found to be resistant to disinfection by free chlorine, and are frequently reported in finished drinking water supplies (AWWA, 1990). And finally, Heterotrophic Plate Counts were assayed to determine the general population numbers of both slow growing (7 day HPC) and fast growing bacteria (48 hour HPC) that are likely related to pathogenic types that may be present in sewage pollution (McFeters, 1990). Ideally, it would have been good to sample for viruses and protozoans as well, but due to the associated time, complexity and high

cost of these analyses, it was deemed to be beyond the scope of this study. For example, a single *Giardia* analysis requires a very large volume of water and can cost several hundred dollars. With these constraints in mind, viruses and protozoal agents were not analyzed for in the samples collected.

The Total Organic Carbon (TOC) content and the Trihalomethane Formation Potentials (THM-FP) were also determined for the samples. Total organic carbon was chosen as a method or assessing organic content in the samples. Linked to this is the trihalomethane formation potential. The theory is that the higher the TOC content the greater the potential the sample has in forming THM's. Trihalomethane concentration was determined for each sample before and after dosing using liquid-liquid extraction with a Hewlett Packard 5790A Series gas chromatograph.

3.1.6 Preparation of Equipment and Supplies

The preparation of the water sampling equipment and preparation for the analytical tests to be performed were completed prior to field trips. All of the media for the microbiological assays was prepared and refrigerated a few days before the field trip. The number of plates to be made were calculated based on the expected number of samples to be collected plus extra additional plates that would be sufficient to cover four or five extra samples. All of the glassware and collection bottles were cleaned and all of the equipment to be used in the microbiological assays were sterilized in an autoclave. Lists of the necessary equipment and supplies necessary for each field trip are included in Appendix C.

3.2 Procedures in the Research Communities

3.2.1 Meet with the Community Guide

After meeting the guide in each community the objectives of the research and the establishment of some sort of sampling and interviewing itinerary for the following day(s) in the community were discussed. Although it was often the case that the sampling portion and the interviewing portion of this research was conducted in unison, the two are discussed separately.

3.2.2 Interview Residents.

Field interviews were conducted with community residents that were willing to share their ideas and experiences in regards to non-conventional drinking water supplies in the study area. People were approached using a snowball sampling referral method (Babbie, 1992). For the most part, the majority of the interviews were obtained with the help of the community guide and were with the people that he or she knew. However, another route tried was to visit to the local health unit in each community and discuss the research with the nurses and CHR's there and ask them for their insights, ideas and suggestions. In addition to the useful information obtained from the Health Center staff, often these people provided the names of suitable individuals who may have relevant information regarding non-conventional drinking water in Northern Alberta.

The interviewing format was informal which had its successes and limitations. Nonetheless, some valuable information was obtained using this surveying method. The interview would typically begin with introductions followed by an explanation of the research and its objectives. After this, a map of the area would be opened onto the table which seemed to foster dialogue. The conversation that followed was directed to include a discussion on the four main areas of interest to the research topic including:

1. Sources and utilization of non-conventional drinking water supplies.
2. Type of treatment, if any, applied to the non-conventional source of drinking water obtained.
3. Their drinking water quality concerns and general water quality concerns.
4. Their perception of how their health has been affected by drinking water quality; both conventional and non-conventional drinking water.

After following this informal format of interviewing for the first field trip, the interview method was altered based on methods described by Babbie (1992). It was thought that a more structured interview would provide grounds for better analysis. So, on the next field trip, one interview was tried in which the questions were asked using the format in Figure 3-2. Ms. Bill was present during that interview and later said that she felt that a less formal surveying format would be better. Therefore, for the remainder of the interviews a less structured format similar to that described above was used.

Throughout the course of all interviews keywords and sentences were written down with permission from those being surveyed. More details were added to the notes immediately after the interviews. Before leaving the place where the interview was being conducted, the persons name and address was obtained so that they could be contacted with the results or with any future questions.

3.2.3 Water Sample Collection

Approximately 4.25 L of water was collected from each sampling location. The breakdown of volume of sample collected for the different analyses was as in Table 3-1.

Table 3-1. Sample Volume Requirements for Analysis.

Analytical Measure	Volume Required
Microorganisms	2 L
Routine Phys-Chem	500 mL
Metals	500 mL
THM Formation Potential	1 L
THM's	50 mL
Odour	200 mL

All of the samples were collected in accordance with methods 9060A of Standard Methods (APHA, 1992). Samples were preserved and stored in accordance with Standard Methods 9060B. Several photographs of each sampling location were taken and the sampling spot was plotted on the map. Variables such as the date, time, method of collection, weather conditions, terrain and type of sample were recorded in the lab book. All sample bottles were clearly labelled before being put into the cooler.

3.2.4 Water Sample Analysis

3.2.4.1 Physical and Chemical Tests in the Field

A few of the parameters were measured immediately at the site of collection. This included temperature, turbidity, and odour. Immediately after the samples were collected and a suitable location was found to set up the other field instruments, the levels of the following parameters were determined: (1) pH, (2) free and combined chlorine, (3) ammonia, (4) colour, and (5) conductivity. A portable Hach Spectrophotometer was used in all of these determinations except for pH in which a portable pH meter was used. The procedures used in these determinations were carefully followed as described in the manuals for the portable instruments used.

3.2.4.2 Microbial Analysis

Since microbial analyses of water samples is required to be done within 24 hours of being collected, samples were packed with ice and couriered back to the University of Alberta Environmental Engineering Lab for analysis immediately after being collected. Even though the microbial analysis was not done in the research communities, a brief discussion of the methods used to enumerate the microorganisms follows.

The membrane filtration technique was used in the microbial analysis of the waters sampled. In this method, samples were filtered through individual sterile membrane filters with a specified pore size rating for the target organism. The membrane filter was then placed on selective media for each organism and incubated for the time specified in Standard Methods (1992). After the incubation period, the colonies formed on the plate were counted and the number of colony forming units (cfu) in the original sample was calculated on a per volume basis. The media, incubation conditions and relevant Standard Methods reference for the microbial analyses performed are listed in Table 3-2.

Table 3-2. Microbial Assay Conditions.

Microbial Parameter	Selective Media	Incubation conditions	Standard Methods (1992) Reference
TC	m-Endo agar	35°C for 24 hours	9222B
FC	m-FC agar	44.5°C for 24 hours	9222D
FS	mE agar	35°C for 48 hours	9230C
Klebsiella	FCIC agar	35°C for 24 hours	9222F
Yeasts	Sabouran Dextrose	20°C for 7 days	9610D
Molds	Rose Bengal	20°C for 7 days	9610D
2 day HPC	R_2A agar	35°C for 48 hours	9215D
7 day HPC	R_2A agar	20°C for 7 days	9215D

3.2.4.3 Other Analyses on the Samples

Acidified samples were sent to an outside lab to be analyzed for heavy metals by Atomic Absorption. Upon returning from the field the TOC of the samples were determined and the Trihalomethane Formation Potential of the first two groups of samples were determined as described in Standard Methods (1992) 5310 and 5710 respectively. The chlorine demand for the samples was determined based on a 3:1 ratio of chlorine to TOC. It was found that this dosing was insufficient to maintain the required chlorine residual after the 7 day reaction period. Therefore, four of the samples were dosed again using a 6:1 Chlorine:TOC ratio. Even at this dose there was insufficient chlorine for the maintenance of a residual.

3.3 Post Field Trip Procedures

Upon returning from the field trip, the remainder of the analyses on the water samples were performed. These included counting the colonies formed on the microbial plates, Total Organic Carbon (TOC) determination, THM Formation potential for the first two sampling sessions and sending the acidified samples away for metals analysis. A follow-up phone call was made to the community guide to thank him or her for their assistance and to clarify any questions. Finally, at the completion of the study, a copy of the research findings were sent to a representative from each community involved in the research to be distributed to interested individuals.

4. FIELD STUDY RESULTS

4.1 Results from Interview Component

During the field trips a total of 28 people were contacted and questioned regarding their experiences with non-conventional drinking water in the NRBS area. Since some of the interviews were conducted in a group setting (with more than one person being questioned at the same time) there were only 19 actual questioning sessions. A total of 16 men and 12 women were interviewed. Table 4-1 gives a breakdown of the general information about the interviews at each site visited.

Table 4-1. General Information about the Field Study Interviews.

	Fort Chipewyan	John D'Or Prairie	High Level, Fort Vermillion and La Crete	Fox Lake	Atikameg	Total
Total Number of Interviews	8	4	3	3	1	19
Total Number of People Questioned	15	4	3	5	1	28
Number of Male Respondents	10	2	1	3	0	16
Number of Female Respondents	5	2	2	2	1	12
Individual Interview Session	3	4	3	1	1	12
Group of 2 Interview Session	4	0	0	2	0	6
Group of 3 Interview Session	0	0	0	0	0	0
Group of 4 Interview Session	1	0	0	0	0	1

The general findings from the interviews will be discussed under each of the three main areas of questioning. These three areas are (1) Drinking Water Quality and Health Related Concerns, (2) Sources of Non-Conventional Drinking Water Utilized, and (3) Non-Conventional Drinking Water Treatment Methods. Due to the informal format of the interviews, the results obtained are qualitative. Therefore, no attempt was made to fit these findings into a statistical model. In addition, the results reflect the individual

responses of people interviewed and do not necessarily reflect the attitudes and practices of all residents in the study area.

It should be noted here that throughout the field study results section, several study area residents are quoted or referenced. Although this may not be the protocol for all scientific papers, the reporting of information in this instance is followed as required in the Northern River Basins Study's (1994) A Guide for the Preparation of Reports. It is written in this document that "personal communications should be handled in the text (of the report)." It also states that "when reference is made to information from a personal communication...the name and identity or address of the communicator (should appear) in parentheses in the text (NRBS, 1994)." Therefore, information obtained from the study area residents is acknowledged and credit is given to the person who contributed to the findings of this research through his or her knowledge.

4.1.1 Drinking Water Quality and Health Related Concerns in the Study Area

From talking to people in the areas visited, it was found that there is great concern over the quality of the drinking water in Northern Alberta. Many of the people expressed an uneasiness about the practice of using chlorine ("Perfex" or "Javex" as it is commonly called) in drinking water treatment. Some people dislike the taste of chlorine so much that they further treat the water to try to remove the chlorine.

Aside from the aesthetic bad taste and odour of chlorine, people in the study area also associate a health risk with drinking chlorinated water. Some people refuse to drink water from the treatment plant because "they think that it would affect them more" than drinking water from the lake (Marten, 1994a). Ms. Marten (1994a) explained that it does not make sense to the people to "dump poison into their drinking water." These same concerns were reiterated at all three study sites. There were several health related concerns regarding the effects of consuming chlorinated drinking water supplies. One

reason given was that the treatment plant water clogs veins. Another reason cited was that drinking chlorinated water causes an allergic reaction resulting in illness. By far the greatest health concern cited by those interviewed was that people felt that the rate of cancer in the study area is rising and this may have something to do with drinking water. The association of drinking water and cancer was discussed by most of the people interviewed in the Fort Chipewyan area. There is certainly some validity to these concerns regarding potential carcinogens in treated drinking water supplies since there have been scientific studies done that suggest that there may be a link between disinfection by-products and bladder cancer (WHO, 1993). However, as stated by the World Health Organization (1993), the microbiological quality of drinking water must take precedence over disinfectant-by-product guidelines in such a way that "disinfection must *never* be compromised."

Besides drinking water from the treatment plant, many residents of the study area obtain drinking water from natural water bodies, particularly those that live in remote locations and live off of the land. Therefore, the people interviewed in this situation had different drinking water quality concerns. These people were not so concerned about chlorine, rather, the poor quality of the lakes and rivers in the area were more important to them. Several of the people talked to attributed the degradation of the surface water to industrial pollution. In the Fort Chipewyan area, people talked about the brown foam that would develop if surface water in the area was used to make tea or coffee. Apparently, the beverages consumed using a water of this nature did not taste very good. It was said that the Athabasca River was particularly polluted and people generally do not use this water for consumption if they can use another source. In the Fox Lake and John D'Or Prairie area, people do not take water from the Peace River anymore because it is "murky" and "polluted" (St. Arnault, 1995). People living in remote areas near these suspected polluted sources have been forced to change their drinking water habits as a result of the perceived poor water quality. One person living in a remote location in Northern Alberta drives to a location 30 minutes away to collect drinking water from a small stream even though his home is located at the mouth of a river.

It is interesting to note that during these field trips, adverse health effects associated with microbial pathogens in drinking water was not a great concern to those interviewed.

4.1.2 Sources of Non-Conventional Drinking Water in the Study Area

All of the sources of non-conventional drinking water mentioned by the interviewees is discussed under the general headings of (1) self-hauled conventionally treated water' (2) surface water; (3) ground water; (4) environmental water; and (5) purchased bottled water. Appropriate examples of the utilization and a general discussion for each of the given types of non-conventional drinking water supplies is below.

4.1.2.1 Self-Hauled Conventionally Treated Water

The reason that this conventionally treated drinking water is included in a list of non-conventional sources of water is because "self-hauled" treated water it is not obtained by the conventional method of distribution. The self hauling of conventionally treated water refers to those individuals that take water from a community tap somewhere in small carrying jugs and transport them to the place of consumption. Therefore, this water can remain out of the distribution system for a longer than recommended time and therefore should not necessarily be considered as a safe treated water supply.

John and Lena Courtoreille from Fort Chipewyan have a cabin on Prairie River about 37 km southwest of Fort Chipewyan. They use this cabin for traditional activities throughout the year such as hunting, fishing and trapping. For the past ten years, they have been hauling treated water from Fort Chipewyan in five and ten gallon containers (Courtoreille, 1994). Hauling treated water in small containers for short "living off the land" expeditions is commonly practiced by many people. In many cases a thermos of tea or coffee may be 'hauled' instead of plain water for day trips. This practice of self-hauling

of treated water in small containers is also practiced in non-native communities and in other parts of the province. For many people living in remote locations, treated water is collected from public buildings, such as the Health Unit or school, and carried back to their homes in small containers.

It is apparent that there are many people in the study area that are burdened by tasks such as hauling water in order to obtain a safe supply of drinking water. Self-hauling from standpipes, treatment plant, nursing station, wells and schools places a heavy burden and inconvenience on the consumer which would tend to keep water consumption low, particularly in the winter (Brocklehurst *et al.*, 1985). Studies have shown that those who must haul water will almost never have all of the water necessary for ordinary demands and decreased quantity of water used has been implicated with poorer health (McJunkin, 1982). Another problem with hauling water in small containers is the potential for contamination. The storing of drinking water for any length of time increases the likelihood of generating large quantities of bacteria. The longer the water is stored, the poorer quality it is likely to be (Gabler *et al.*, 1988). From one of the locations visited where water was being hauled in 5 and 10 gallon containers, it was sitting at room temperature and the residents would haul enough water to last them for a week at a time. In order to prevent excessive bacterial growth in water stored outside the distribution system, it is recommended to refrigerate the water and not to let it sit for more than two days before consumption (Gabler *et al.*, 1988). This obviously has its limitations in situations such as these where refrigerator space is limited or non-existent, and long excursions to the treatment plant for more water every second day is impractical.

4.1.2.2 Surface Water

Surface water includes lakes, rivers, ponds, streams, reservoirs, dugouts and any other body of water that has direct contact with the atmosphere.

Lake, River or Creek Water. There are many people in the study area that profess that they drink the water directly from lakes, rivers and creeks. A few of the examples of residents claiming to drink untreated lake or river water are numerous and are described below. As a child, Terry Marten (1994b) and her family lived off of the land following the animals in the Peace-Athabasca Delta. She recalled that sometimes they would obtain their drinking water from a nearby lake or river and drink it untreated. Raymond and Yvonne Ladoucer (1994) have a cabin at Big Point on Lake Athabasca. They obtain their drinking water from Keane River which he says is crystal clear and does not need any treatment whatsoever. He drives to a remote location on Keane River and collects 25 to 35 gallons at a time. This will generally last them 4 or 5 days. Each year there is a pilgrimage event at Little Red River near Fox Lake in which hundreds of people attend. Even though there is a drinking water truck at the event, many people choose to drink the water right from the river as has been done in the past (Laboucan, 1994). One resident who was at the event in the summer of 1993, mentioned that the water from the river was "very good" even though this individual said that he had diarrhea all the way home from the event. The cause of this persons diarrhea could have been the result of so many factors, but one would have to consider a waterborne illness. Yet, it should be noted that none of the other people interviewed who used untreated surface water said that they had suffered ill-health as a result of drinking untreated water.

Brocklehurst *et al.*, (1985) state that "self haul from lakes or creeks has all the disadvantages of handling, storage and low consumption plus the obvious problem that the water is usually contaminated at the source." It is well established that surface waters are not free from pathogenic risks. Even pristine waters (protected from human activity) have been found to contain pathogenic organisms (Rose *et al.*, 1991). This is because microorganisms that are pathogenic to humans can also be carried by animals. For example, *Giardia lamblia* is a human parasite that has also been found in beavers, muskrats, dogs, cats, deer, and rodents to name a few (Hibler and Hancock, 1990). Birds and waterfowl can also be a source of microbial contamination.

Another aspect that must be considered is that the sanitation in remote areas is generally with pit privies which are often poorly constructed and maintained. Runoff from these privies may result in the fecal contamination of nearby lakes and creeks (Brocklehurst *et al.*, 1985). A situation like this was noted in a remote area in the Peace-Athabasca Delta. An improperly constructed outhouse allowed small animals to scatter toilet paper and human waste in the surrounding area. It is possible that this debris could have made its way into the nearby lake or could have percolated into the nearby newly constructed well. Furthermore, garbage wastes in this same location had also been haphazardly disposed of, and may have contributed significant pathogen releases to non-conventional source waters.

As a result of the potential pathogens that exist in untreated surface waters, consuming raw lake or river water is certainly a risk factor for acquiring a waterborne disease. A lack of treatment, or inadequate treatment accounted for the majority of the waterborne disease outbreaks reported in the United States in 1991 and 1992 (Moore *et al.*, 1994). Based on the fact that there are people who claim to drink untreated water in the study area, this statement can probably be applied to Northern Alberta as well.

Dugout Water. There are many dugouts in the Northern River Basins Study area. Dugouts are a popular source of water in rural remote areas where groundwater is of poor quality, of limited quantity, or unavailable altogether (Alberta Agriculture, 1988). Dugouts are basically a large excavated hole in the ground that acts as a water reservoir. Water from the dugout that is pumped into the home typically undergoes some form of treatment prior to consumption, either at the point-of-entry or the point-of-use. The treatment process employed is dependent on the raw water quality, the volume of water to be treated and the economics involved. Dugout water has all of the problems associated with most surface water supplies; and then some. It is important that many factors are considered when designing a dugout including the nature of the drainage area, the soil type, areas of potential contamination, distance to point of use and daily water

requirements (Alberta Agriculture, 1988). Some of the common drinking water quality problems associated with dugouts is presented in Table 4-2 along with possible treatment strategies.

Table 4-2. Common Dugout Water Quality Problems and Solutions

Water Quality Problem	Cause	Treatment at Dugout	Treatment at House
Microbial Contamination	Agricultural Runoff	Use ditches and dikes to divert objectionable runoff	Filtration and Disinfection
	Domestic Sewage Contamination	Locate dugout away from domestic waste discharges	Filtration and Disinfection
	Direct contamination by animals	Put a fence around the dugout	Filtration and Disinfection
Turbidity (Suspended Material in the water)	Erosion from the watershed	Plant grass in the waterways and area around the dugout	Filtration
	Storm Runoff	Spread 10 lbs of alum per 100000 gallons of water on surface. Let settle.	Filtration
Taste, Odour and Colour	Algae	Apply 1 lb copper sulfate per 100 000 gallons water in spring, summer and fall.	
	Water Weeds	Apply herbicide	Do not consume for 24 hours after herbicide applied
	Decomposing Organic Material	Aerate and keep trees 100 feet from dugout edge.	
	Iron and iron bacteria		Filtration and Disinfection
Hardness	Calcium and Magnesium ions		Water Softener

(adapted from Alberta Agriculture, 1980)

Watering Hole. A watering hole is essentially a community dugout. All of the same elements are involved except that water is treated at the site (if at all) instead of in the individuals home, and water trucks are used to transport water to the point of use. There are several watering holes in the High Level area that are set up to take the demand off of the municipal drinking water treatment plant from farmers that need to water livestock. Although it is clearly marked that the water is not meant for human consumption unless boiled, an Environmental Health Officer from High Level suspects that some people may use this as their drinking water source.

4.1.2.3 Groundwater

It seems as though groundwater is a favoured source of drinking water for some people living in the study area. Groundwater is contained in porous spaces in rocky material below the surface and moves in areas called aquifers. Groundwater has long been considered to be of good quality, because the soil barrier acts as a protection from surface pollutants (WHO, 1993). However, it is not impossible for groundwater to become polluted. There are many modes of entry of pollution into groundwater supplies. These include direct injection through a well, leaching through the soil and infiltration of polluted surface water sources among others (WHO, 1993)

In order to use groundwater as a source of drinking water, it must somehow find its way to the surface. Sometimes this occurs naturally as is the case with artesian wells or springs. Other times, groundwater remains in the aquifer until the water is drawn out by a pump through a well.

Spring Water. A spring is defined as an opening in the ground surface from which groundwater freely flows (USEPA, 1974). Artesian wells or springs occur where the water table comes into contact with the atmosphere or through faults in rock layers through which water from an aquifer can trickle up. There is a groundwater spring between John D'Or Prairie and Garden River that is considered sacred by local residents. Many people from John D'Or Prairie travel 37 km to this spring to collect their drinking water. This particular spring resulted in a fairly large reservoir of water that collected in a nearby depression. Therefore, although this water originated from the ground, its contact with the atmosphere means that it is susceptible to contamination typical of surface waters.

It is possible to protect spring water sources by building structures to encase the supply of water coming from the spring. The main components of a spring encasement structure include a system of perforated collection pipes, a covered impermeable storage tank and a

method of collecting the water. Other important features include the provision of a surface water diversion ditch, allowance for overflow from the spring and provision for cleaning and emptying the tank when necessary.

Well Water. There are many groundwater wells in the NRBS area that are used for household drinking water supplies. In most instances, groundwater wells utilize specialized drilling equipment that has replaced the pick and shovel method of reaching the water table. However, there are still people in the Fox Lake area that live off of the land who obtain drinking water from very shallow hand dug wells. Apparently, when hunters are in the wilderness, they will dig a two foot hole in the ground and wait for the water to seep up into the hole so that they can collect it to drink it (Laboucan, 1994). Although, by definition this is a groundwater well, it is a primitive one and technology today has allowed for the extraction of water from very deep and protected aquifers. Waters extracted from these "well protected aquifers are usually free from pathogenic microorganisms and the distribution of untreated groundwater is a common practice in many countries (WHO, 1993)."

Groundwater has long been considered a desirable source of domestic water. There are probably many groundwater sources in the study area that meet the Canadian Drinking Water Quality Guidelines without any treatment at all. But, aquifers can become contaminated and sometimes the natural levels of certain inorganic chemicals are high enough to constitute a risk to health. If groundwater was used in this case, treatment may be required. An example of this was a well in the Fort Vermillion area that serves about 15 people. It had been found that the well water had a nitrate concentration that exceeded the health limit set in the Guidelines for Canadian Drinking Water Quality (Bingham, 1994). The source of the contamination was uncertain but could have been the result of a number of factors including sewage contamination, surface water infiltration, or leaching of nitrates from decomposing organic matter nearby. It has been suggested by the Northwestern Health Unit that the families affected invest in a reverse osmosis treatment

unit which is effective at removing nitrates (Bingham, 1994). This would be a valid application of effective point-of-use technology.

If available, well water can be an excellent alternative for people that live in remote areas. A well can be located so that hauling in minimized, there is an adequate quantity available and the quality is generally very good so treatment, if any, is minimal.

4.1.2.4 Water from Other Environmental Sources

Although all water is from the environment, a separate heading called *Water from Other Environmental Sources* is included for some of the less common raw drinking water sources in Canada that are not obviously surface or groundwater. In this thesis, water from other environmental sources is considered to be any water that is obtained from entities such as snow, ice, rain, trees or the muskeg.

Snow Water. In the winter time, snow is a popular source of non-conventional drinking water in the study area, particularly for trappers. But trappers are not the only ones that melt snow for drinking water. Supposedly, one lady living near Rocky Lane in the Peace River Basin collects snow in her cistern all winter so that she will be able to drink snow water in the summer months (Bingham, 1994). Also, after a recent water main break in Atikameg, people on the piped distribution system were without treated water until the problem was solved. A nurse in the area said that she thought that many people were using snow for water during this time (Schleifer, 1995).

Ice Water. The winter ice cover on lakes and rivers is another source of non-conventional drinking water in Northern Alberta. Saws, chisels and axes are used to cut out blocks of ice (St. Arnault, 1995; Chalifoux, 1995). Although chainsaws make this job much easier, they are not always used because they tend to leak oil and grease onto the ice and into the water (St. Arnault, 1995). Chalifoux said that the blocks taken from Utikuma Lake near

Atikameg are usually about one square foot, but with some of the new equipment available, larger blocks can be made. Once the blocks are made, they are hauled out of the water using a rope and a ramp and taken to the house to be melted for water or stored to be used later (Health and Welfare Canada, 1973).

The quality of the water obtained from the ice blocks will be about the same as the quality of the lake or river that it covers. Since microorganisms are generally capable of surviving freezing temperatures, it should be assumed that the ice water is contaminated and appropriate precautions should be taken, such as boiling the water for tea or coffee.

Lester St. Arnault gave a good example of the changing quality of the ice water obtained from the Peace River. He said that people from the Little Red River Cree Band used to use ice from the Peace River for their drinking water. "Now," he says, "the water you get from the ice is murky." It has sediment and it is not as clear as it used to be. In the past the ice was a bluish color before it was melted and after it was melted the water was clear. Now, the ice is cloudy, the water is dirty and people don't use it so much anymore (St. Arnault, 1995).

Rain Water. Rain water harvesting as a source of water for domestic consumption has been practiced throughout the world for many years (Mayo and Mashauri, 1991). Apparently, the Northern River Basins Study area is no exception. Lester St. Arnault (1995) of John D'Or Prairie said that it is "quite common to see barrels around for collecting rain." Rain water is collected in 45 gallon barrels in the spring and summer months. One person who was asked about this practice in the north said that using rain as a source of drinking water is not as common as it used to be because people are afraid of the acid rain.

A 1974 USEPA document stated that precipitation in the form of rain, snow, hail, and sleet contains very few impurities. Although it may contain trace amounts of mineral matter, gases, and other substances, it has virtually no bacterial content. However, once

the precipitation reaches the surface of the earth, there are many opportunities for the introduction of chemical and microbial pollutants (USEPA, 1974). A study in Tanzania assessing the quality of rainwater for consumptive purposes showed that 45% of the samples collected were contaminated with Total Coliforms, 14% with Fecal Coliforms and 53% with Fecal Streptococci (Mayo and Mashauri, 1991). The reason for this contamination was due to the improper collection and storage of the water. The quality of the collected rainwater was influenced by the quality of the precipitation, deposition on the collection surfaces and the introduction of other contaminants into the system (Mayo and Mashauri, 1991).

Birch Tree Water. A traditional non-conventional source of drinking water is available every spring in some areas. In April and May, birch trees are tapped for "really good drinking water (St. Arnault, 1994)." A 10 mm deep and 50 mm long incision is cut on a slant on the bark of a fairly large diameter birch tree. A twig is placed in this incision to act as a tap so that the water can drip into a bucket below. The next morning about 12 litres of the Birch-water is collected (St. Arnault, 1994). The water is sweet tasting and can be made into molasses (Bill, 1994). Other trees such as the poplar can also be used, but the water from the poplar is much foamier. After the water is collected, the incision is sealed back up with spruce gum so that the tree does not get an infection. The following year, a different tree is used so that the tree does not become stressed and die (St. Arnault, 1994).

Muskeg. The muskeg is soft spongy moss covered ground found in many areas of the Peace, Athabasca and Slave River basins (Fraser, 1994; Chalifoux, 1995). The ground below the muskeg is saturated with water. This coupled with the fact that moss is relatively impermeable to water means that if water somehow gets on top of the muskeg, it is retained there until it slowly seeps through or until it evaporates. Sometimes, fairly large pockets of water can accumulate in the muskeg, especially after a rain event which not only contributes water directly but which also recharges the groundwater thereby raising the water table.

One resident from Fort Chipewyan talked about a family camping trip every summer in which the potable source of water comes from the muskeg (Fraser, 1994). Muskeg water has a slightly acidic taste. Some people think that muskeg water has medicinal properties. As mentioned, some people in the community think that conventional "treatment water" will clog their veins. It is thought that the cure for this clogging is to drink muskeg water which is an effective de-clogger.

Although some of the water found in the muskeg may have originated from the ground, it is essentially subject to many of the same pollutants that surface water would be. Due to its proximity to the soil and vegetation, it is likely to be laden with microorganisms in some cases. Therefore, most public health agencies would probably recommend boiling muskeg water before consumption.

4.1.2.5 Purchased Bottled Water

Although it is difficult to assess the utilization of bottled water in the Northern River Basins on an individual basis, it is definitely available to consumers there. During field trips during the course of this study, all of the stores visited had a selection of bottled waters in their refrigerators. One person interviewed in the study area purchased special bottled water for her son because she felt that the conventional drinking water supply would have an adverse affect on his health.

Bottled water consumption in North America is increasing at a rate of 25% per year (Smith, 1994). It has been hypothesized that the sale of bottled water has skyrocketed anywhere where the public suspects that the local water supply is contaminated. Since the price of bottled water is 500 to 1000 times more expensive to buy than tap water, selling bottled water has become a profitable business (Gabler *et al.*, 1988). There are many types of bottled waters on the market today.

1. Still water is any bottled water that is not carbonated. It can be natural or it can be treated.
2. Sparkling water is carbonated with carbon dioxide.
3. Spring water comes from a groundwater spring. Spring water can be naturally carbonated or carbon dioxide may have been added by the bottler. The word "natural" in the product name means that the water has not been processed in any way.
4. USP purified water is pharmaceutical grade water that meets the standards of the United States Pharmacopoeia.
5. Mineral water is water that contains a certain concentration of dissolved salts. Sources of mineral water can be spring, still, drinking or purified water. The salts can either be those present in the original water source or they may have been added.
6. Distilled water is any type of water that has been evaporated and condensed.
7. Bottled drinking water implies nothing about the source. It can be from a spring, a well, a lake, a river or a household tap and it may have been processed in some way. It is basically water in a bottle.

Although in some instances, bottled water may have been marketed as the epitomy of healthy drinking water, this is not necessarily the case. The general bacterial counts of some bottled waters can be particularly high and, the longer that the bottled water sits, the higher the bacterial count becomes (Geldreich *et al.*, 1978; Smith, 1994). Carbonated brands may not have counts as high as uncarbonated varieties because carbonation lowers the pH which is effective at killing some strains of bacteria (Gabler *et al.*, 1988). Bacteria is not the only problem though. Organics can enter bottled water in several ways. First, the raw water source used for the bottled water may contain organics. Second, organics can somehow inadvertently be added by the bottler. An example would be by bottlers that use chlorine in their disinfection process, thereby producing chloroform as a by-product. Third, organics in bottled water can be leached from the bottle itself. Most bottled water

comes in plastic bottles. "Among the organics that leach from plastic bottles are plasticizers used to keep the bottle flexible, mold-release compounds used to get the bottle out of the mold when it is made, and unreacted plastic material itself (Gabler *et al.*, 1988)."

In addition to the high general bacterial counts and the potential organic problem in bottled waters, there have also been reports of excessive mineral levels in some brands. For the most part, the inorganic mineral content in bottled water is generally low. However, some brands of mineral water may not meet inorganic chemical standards, with sodium notable in the group (Gabler *et al.*, 1988).

4.1.3 Non-Conventional Drinking Water Treatment in the Study Area

Boiled Surface Water. When respondents were asked about whether the non-conventional source of water that they collected was treated in any way, many people said "No" and many others said that they used the water to make tea or coffee. Herbal teas made from berries, or the stems, leaves or bark of shrubs is a traditional beverage of most native people and is still widely consumed today (Health and Welfare Canada, 1985). One person in the study area suggested that when people are living off of the land that they probably drink tea 90% of the time and "to make good tea, the water needs to be boiled (Marten, 1994a)." This statement is backed up by the findings of the NRBS Traditional Knowledge on a question about what lake and river water was used for. Ninety-six percent of the respondents indicated that they would use lake and river water to make tea or coffee (Traditional Knowledge Component, 1995).

When asked about the length of time that the water was boiled to make tea, all of the people questioned responded that as soon as the water started boiling it was ready. A question regarding the length of time boiling may not provide accurate information,

because in most cases people probably do not keep track of the exact amount of time that the water is boiling. In any case, boiling has proven to be a reliable treatment method for the removal of microbial pathogens and the fact that 'good tea' requires that the water is boiled should also ensure that the water/tea is safe to drink.

Despite the low level of technology required for treatment by boiling, there are several drawbacks that limit its usefulness. The primary one is the requirement of fuel to heat the water. This fuel can be wood, coal or some other form. In any case, if the fuel is at a premium, then so is the availability of potable drinking water. Another drawback is that although boiling water will improve the microbiological quality of drinking water, the aesthetic quality of the water is not improved by boiling. Colour will not be removed and often the taste is compromised.

Nonetheless, boiling water is perhaps the best and most effective method of purifying water of questionable quality and when in doubt, water should be boiled. Boiling times are varied in the literature as evidenced by the figures presented in Table 2-1.

Chemical Addition

None of the people interviewed claimed to add any chemicals (such as chlorine or iodine) to their non-conventional source of drinking water prior to consumption. If anything, it was the chemicals in conventionally treated water, chlorine in particular, that may have prompted many people to search for alternate water supplies. During the interviews there was a noticeable aversion to the addition of chemicals to drinking water by most of those surveyed.

Simple Aeration for Volatile Organics Removal

In some cases in the Northern River Basins Study area, residents felt that the bad taste and odour of chlorine ("Perfex" or "Javex") in their drinking water could be combatted by a simple aeration point-of-use treatment. In one of the households visited, the occupants aerated their conventionally treated water overnight so that the taste and odour of chlorine would dissipate. They did this by collecting about two litres of water in a plastic container and letting it sit on the counter overnight before consumption. Although this is an effective method of removing volatile organics and chlorine, ideally water should be consumed immediately after treatment to prevent deterioration (Gabler *et al.*, 1988). This is because some types of microorganisms can grow in almost any water, especially at warm temperatures (Health and Welfare Canada, 1985b).

Point-of-Use Water Treatment Devices

Only one person was interviewed who was utilizing a point-of-use device to further treat the conventional drinking water coming to her household tap. The unit that she was using was an NSA Activated Carbon filter that treated water by the cupful. She was using this unit to "get rid of the chlorine". The activated carbon filter had been in use for approximately 6 months at the time of interviewing and the filter had not been changed yet. It is difficult to determine what other water treatment devices are in use in the study area due to the limited number of interviews conducted.

Several people interviewed who were involved in living off the land activities described a simple point-of-use "device" often used to filter drinking water. The POU article was a piece of cloth. Several methods of using cloth to filter the water were described. One person used a special cloth bag and poured water into it as if it was a jug and collected the effluent in a container below. Another method was to place the fabric over the opening

of a jar containing untreated water and pour the water through the cloth into another container.

It would be remiss to exclude the utilization of package drinking water treatment plants (package plants) in Northern Alberta. Although these types of systems typically involve conventional drinking water treatment processes, they are mentioned here because often these package plants are often used in conjunction with a non-conventional drinking water source. For example, many homes with dugouts may have a package plant that treats the water prior to consumption. Since no interviews were conducted at homes where a dugout was used, it is difficult to comment on the types of package plants in use. However, it is probably safe to say that some homes have highly technical water treatment equipment using several processes, while others treat their water with simpler package plants and fewer processing steps.

4.2 Results from Water Sampling Component

4.2.1 Sampling Sites

Figures 4-1 to 4-3 show where non-conventional drinking water samples were taken from during the course of this study. The sampling spots were chosen with the guidance of residents in the area based on where people obtained drinking water outside of the conventional drinking water treatment plant.

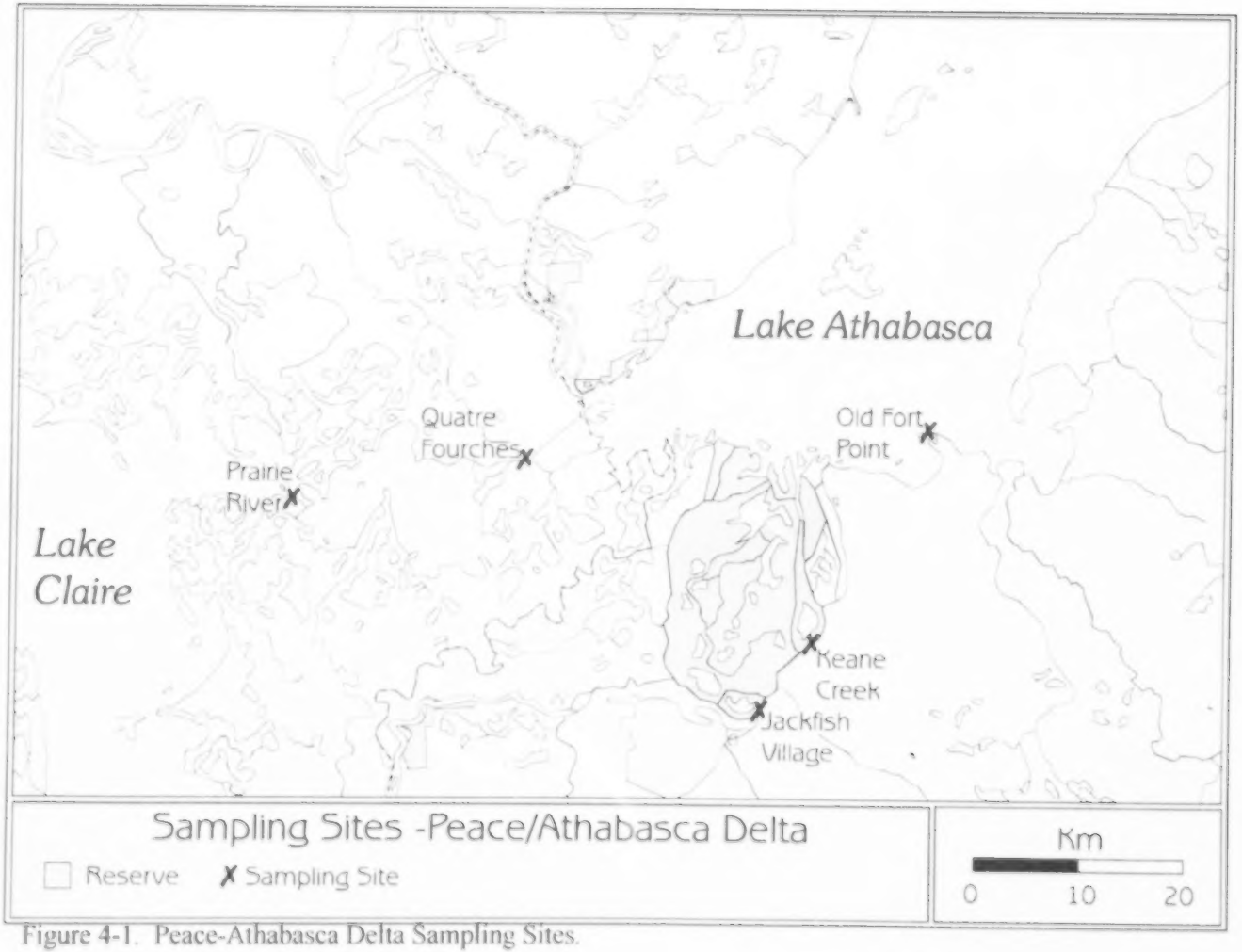


Figure 4-1. Peace-Athabasca Delta Sampling Sites.

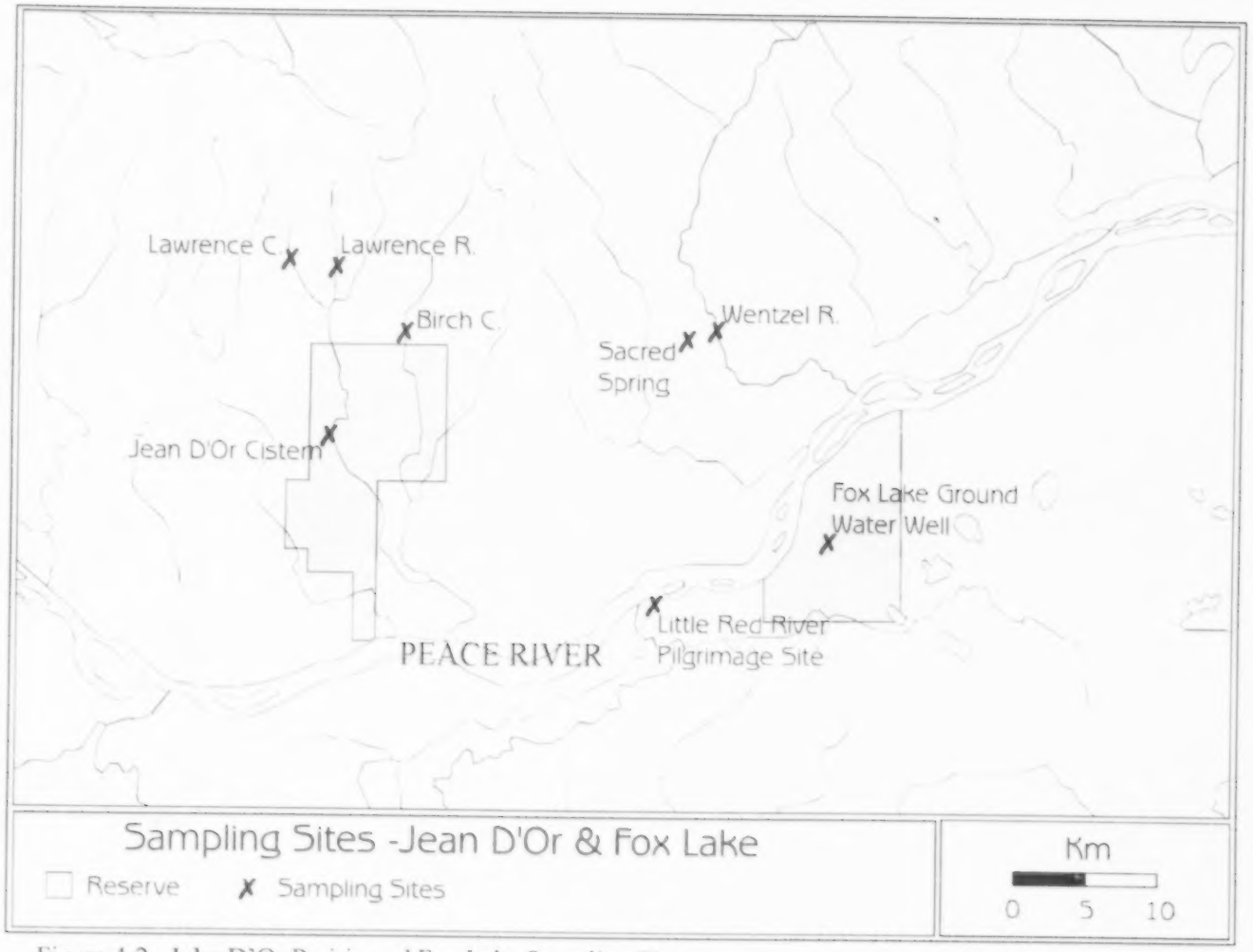


Figure 4-2. John D'Or Prairie and Fox Lake Sampling Sites.

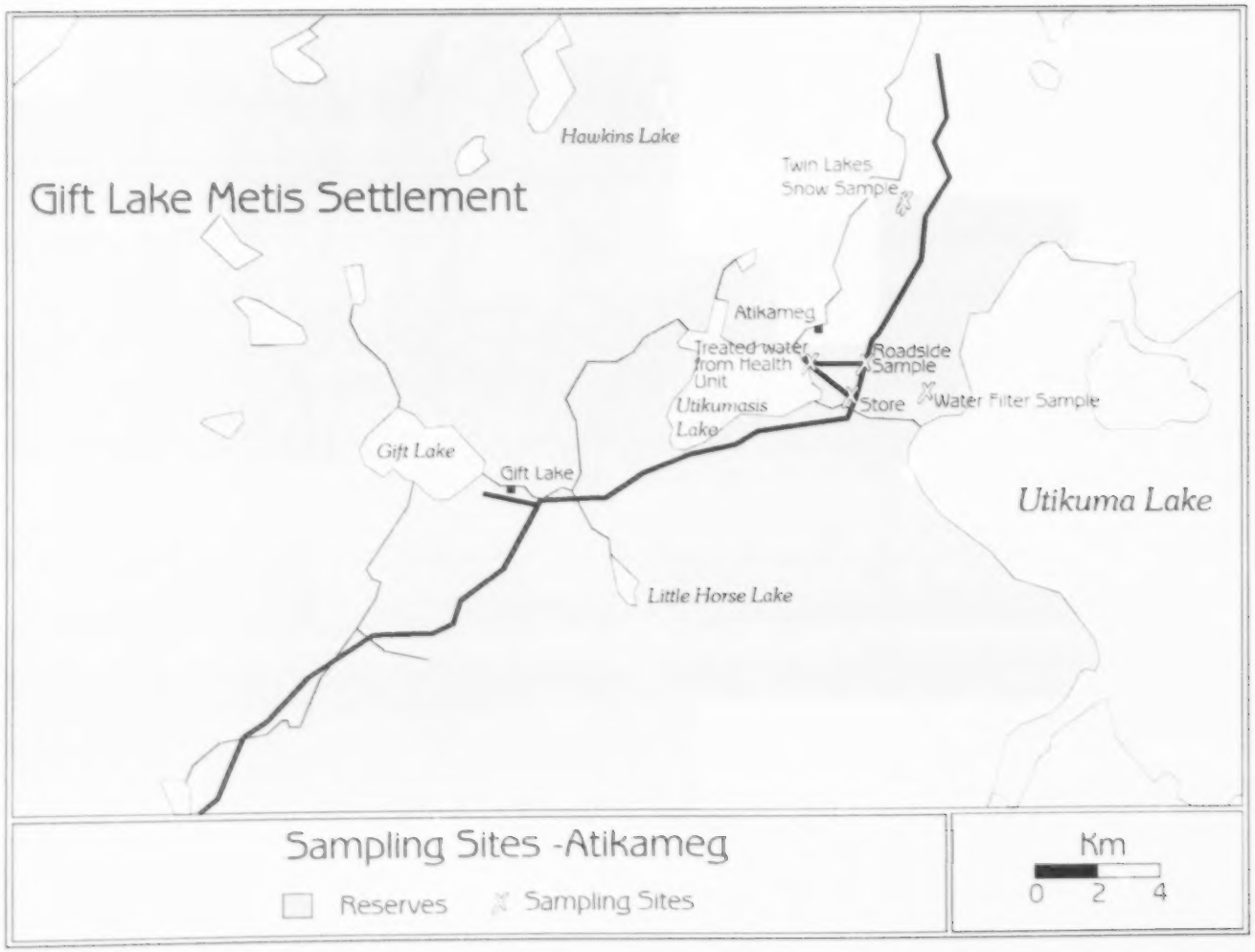


Figure 4-3. Atikameg Sampling Sites.

4.2.2 Analysis of Water Samples

The results obtained from the water sampling portion of this study are presented in a series of tables in the pages that follow.

4.2.2.1 Treated Water Samples

The assessment of the conventionally treated water can be used as a reference for assessing some of the non-conventional sources of drinking water. The results of the analysis performed on treated drinking water supplies are presented in Table 4-3. The microbiological MAC guidelines are met for the conventional drinking water samples obtained from the Atikameg Health Unit and the John D'Or Prairie Cistern. However, it should be noted that the free chlorine concentration found at the John D'Or Prairie cistern is below 1.0 mg/L. This low chlorine concentration also explains the significantly higher levels of HPC bacteria and yeasts and molds at the John D'Or Prairie site than that seen in the treated water at Atikameg. The drinking water from the John D'Or cistern should be resampled to see if the free chlorine concentration is low again. The trihalomethane MAC guideline value is 100 μg/L for treated drinking water. This has been exceeded in the John D'Or Prairie Cistern raw water. In addition, some aesthetic related guidelines have been exceeded in the conventionally treated water from both locations, notably iron and colour.

The effectiveness of one type of POU treatment device being used in Atikameg can be assessed by looking at samples of the influent water (in this case the Atikameg Health Unit Sample) and comparing the results with the effluent water labelled Atikameg POU Treatment Filter. This particular unit was effective at reducing the turbidity, the chlorine taste, the free chlorine residual, the total chlorine residual and the total organic carbon. Due to these capabilities, researchers are led to believe that the active ingredient in this unit is activated carbon. This is supported by looking at the microbial data. Although the concentration of coliforms in the influent was less than 1 cfu/100 mL, the

concentration in the effluent from this unit had 9 cfu/100 mL. An increase in other microbial parameters were also seen including yeasts, molds, and the general bacterial population. It appears as though these bacteria have colonized the treatment filter and are released into the effluent water in higher concentrations than were in the influent water As a result of this, the treated water no longer meets the microbial limits set in the GCDWQ. Therefore, without proper maintenance and frequent replacement of these filters, point-of-use devices such as these may constitute an additional risk to health.

Table 4-3. Results from Treated Water Analyses.

(a) Physical and Chemical Parameters

Sample	Date	pH	Turbidity NTU	Odour subjective	Conduct umhos/cm	Colour TCU	Ammonia $mgNH_3$-N/L	Free Cl_2 mg/L	Total Cl_2 mg/L	TOC mg/L
John D'Or Cistern	Nov 4/94	8.0	0.3	chlorine	500	15	0.013	0.02	0.05	10.7
Atikameg Health Unit	Feb 28/95	6.81	0.76	chlorine	430	40	0.01	1	2	9.65
Atikameg POU Treatment Filter‡	Feb 28/95	6.86	0.4	None	375	30	0.01	0.05	0.27	2.64

(b) Metals Analysis

Sample	Date	B ug/L	As ug/L	Ba ug/L	Cd ug/L	Cr ug/L	Cu ug/L	Fe mg/L	Mn ug/	Pb ug/L	Hg ug/L	Zn ug/L
1993 Canadian Drinking Water Quality Guideline		IMA 5000	IMAC 25	MAC 1000	MA 5	MA 50	AO ≤100	AO ≤0.3	AO ≤50	MA 10	MA 1	AO ≤500
John D'Or Cistern	Nov 4/9	30	<1	46	<1	<1	16	0.6	13	1	1	20
Atikameg Health Unit	Feb 28/9	<1	<1	24	<1	<1	88	11	11	<1	<1	<1
Atikameg POU Treatment Filter	Feb 28/9	<1	<1	22	<1	<1	7	10	15	<1	<1	<1

(c) Microbial Parameters

Sample	Date	TC cfu/100mL	FC cfu/100mL	FS cfu/100mL	*Klebsiella* cfu/100mL	Yeasts cfu/100mL	Molds cfu/100mL	48hr HPC cfu/mL	7d HPC cfu/mL
John D'Or Cistern	Nov 4/94	<1	<1	<1	<1	1.0×10^3	8.4×10^2	3.6×10^1	3.6×10^1
Atikameg Health Unit	Feb 28/95	<1	<1	<1	<1	<1	<1	<1	<1
Atikameg POU Treatment Filter	Feb 28/95	9.0×10^0	<1	<1	<1	1.3×10^3	2.0×10^2	3.3×10^1	3.3×10^1

‡ Not considered to be Conventionally Treated Drinking Water because this water has been further treated at the point of use with an indivually owned treatment device.

4.2.2.2 Surface Water Samples

The results from the tests done on the surface water samples are presented in Table 4-4. There are many physical, chemical and microbiological parameters in the surface waters tested that do not meet the guideline values recommended in the GCDWQ (Federal-Provincial Subcommittee on Drinking Water, 1993). Based on this, drinking untreated surface water could pose a serious threat to health. All of the samples collected were positive for total coliforms which are used as an indicator of the pathogenicity of water. In addition, the general bacterial populations are fairly high.

The turbidities of the surface water samples were highly variable ranging from 3 NTU to more than 100 NTU. Therefore, none of the surface water samples meet the MAC for turbidity (unless it can be shown that disinfection at Little Red River and Wentzel River would not be compromised by turbidities of 3 and 5, respectively).

The metals analysis of the surface water samples indicate that if the water from Lawrence Creek, Lawrence River, Birch Creek or Little Red River was consumed over a lifetime without treatment, that there would be a health risk due to the consumption of mercury. Mercury is found in two forms in the aquatic environment. In the water phase, mercury is an inorganic salt that is poorly adsorbed in the gastrointestinal tract. However, sediments and fish contain organic methyl mercury that targets the central nervous system and can cause impaired mental and motor functions or even death (AWWA, 1990). Mercury can occur naturally or as a result of pollution. Due to the remote areas where these samples were collected, it is deduced that the area around John D'Or Prairie has naturally high levels of environmental mercury. Manganese was also exceeded in several of the surface water samples but manganese is only regulated for aesthetic purposes.

Table 4-4. Results from Surface Water Analyses.

(a) Physical and Chemical Parameters

Sample	Date	Temp °C	pH	Turbidity NTU	Odour subjective	Conductivity umhos/cm	Colour TCU	Ammonia $mgNH_3$-N/L	TOC mg/L
Sand Point	Sept 27 / 94	-	7.9	16	none	85	20	0.012	-
Old Fort Point	Sept 27 / 94	10	8.2	41	muddy	300	65	0.117	6.7
Keane River	Sept 27 / 94	9	7.7	11	muddy	125	35	0.05	5.0
Jackfish Village	Sept 27 / 94	12	8.1	7.4	none	330	52	0.043	5.9
Prairie River	Sept 28 / 94	8.5	8.1	>100	muddy	560	280	0.4	19.7
Quatre Forches	Sept 28 / 94	10	8.1	17	chemical	295	90	0.025	5.6
Lawrence Creek	Nov 1 / 94	0	7.8	27.5	wood-none	1780	40	0.043	29.0
Lawrence River	Nov 1 / 94	0.5	8	5.5	grass-none	700	125	0.027	15.7
Birch Creek	Nov 1 / 94	1	7.5	19	salt-sulfur	1250	55	0.075	11.4
Little Red River	Nov 2 / 94	0	7.3	3	none	350	235	0	23.2
Wentzel River	Nov 4 / 94	0.5	7.9	5	swamp	570	90	0.075	17.3

(b) Metals Analysis

Sample	Date	B ug/L	As ug/L	Ba ug/L	Cd ug/L	Cr ug/L	Cu ug/L	Fe mg/L	Mn ug/L	Pb ug/L	Hg ug/L	Zn ug/L
1993 Canadian Drinking Water Quality Guideline		IMAC 5000	IMAC 25	MAC 1000	MAC 5	MAC 50	AO ≤1000	AO ≤0.3	AO ≤50	MAC 10	MAC 1	AO ≤5000
Sand Point	Sept 27/94	<1	1	14	<1	<1	<1	0.4	22	<1	<1	4
Old Fort Point	Sept 27/94	5	2	54	<1	<1	2	1.2	67	2	<1	5
Keane River	Sept 27/94	<1	<1	12	<1	<1	<1	0.7	40	1	<1	2
Jackfish Village	Sept 27/94	6	1	47	<1	<1	2	0.3	24	<1	<1	1
Prairie River	Sept 28/94	55	4	95	<1	<1	12	5.2	270	4	<1	23
Quatre Forches	Sept 28/94	5	1	49	<1	<1	2	0.7	28	<1	<1	3
Lawrence Creek	Nov 1/94	110	6	63	<1	<1	23	6.8	2400	5	2	32
Lawrence River	Nov 1/94	53	1	56	<1	<1	6	1.0	21	<1	4	1
Birch Creek	Nov 1/94	150	1	28	<1	<1	10	1.5	810	1	1	16
Little Red River	Nov 2/94	25	1	33	<1	<1	6	1.0	21	<1	4	1
Wentzel River	Nov 4/94	36	<1	60	<1	<1	3	<1	22	<1	<1	3

(c) Microbial Parameters

Sample	Date	TC cfu/100mL	FC cfu/100mL	FS cfu/100mL	*Klebsiella* cfu/100mL	Yeasts cfu/100mL	Molds cfu/100mL	48hr HPC cfu/mL	7d HPC cfu/mL
Sand Point	Sept 27/94	1.0×10^{0}	<1	2.0×10^{0}	5.0×10^{0}	1.9×10^{3}	1.6×10^{2}	4.0×10^{0}	2.6×10^{2}
Old Fort Point	Sept 27/94	TNTC	<1	1.4×10^{1}	?	9.2×10^{3}	3.0×10^{3}	1.2×10^{2}	2.0×10^{3}
Keane River	Sept 27/94	TNTC	<1	3.3×10^{1}	<1	3.6×10^{4}	3.4×10^{3}	3.6×10^{2}	1.6×10^{3}
Jackfish Village	Sept 27/94	6.0×10^{0}	<1	5.0×10^{0}	<1	2.2×10^{3}	1.4×10^{3}	5.0×10^{1}	2.2×10^{2}
Prairie River	Sept 28/94	3.0×10^{0}	<1	5.9×10^{1}	Confluent	1.5×10^{4}	1.4×10^{3}	5.8×10^{1}	4.7×10^{2}
Quatre Forches	Sept 28/94	1.0×10^{1}	<1	1.0×10^{0}	<1	9.1×10^{3}	1.6×10^{3}	2.3×10^{1}	5.7×10^{2}
Lawrence Creek	Nov 1/94	7.0×10^{0}	<1	6.0×10^{0}	<1	1.3×10^{3}	4.2×10^{3}	4.4×10^{1}	2.8×10^{3}
Lawrence River	Nov 1/94	2.4×10^{1}	<1	3.0×10^{0}	<1	3.6×10^{3}	2.1×10^{3}	2.3×10^{1}	2.0×10^{3}
Birch Creek	Nov 1/94	4.2×10^{1}	<1	2.1×10^{1}	<1	6.1×10^{4}	4.4×10^{3}	5.4×10^{1}	5.3×10^{3}
Little Red River	Nov 2/94	6.5×10^{1}	2.0×10^{0}	<1	<1	1.5×10^{3}	2.0×10^{3}	5.0×10^{1}	3.6×10^{2}
Wentzel River	Nov 4/94	2.2×10^{1}	2.0×10^{0}	<1	<1	7.3×10^{3}	5.6×10^{3}	1.4×10^{2}	1.1×10^{3}

Raw water quality in any surface water source is highly variable at best. There are so many factors that can influence the quality of the water. For example, surface water quality is influenced by the occasional recirculation of organisms trapped in bottom sediments. Studies have shown that there can be a 100 to 1000 fold increase in fecal coliform bacteria in the bottom sediments compared to the overlying waters (McFeters, 1990). This recirculation may become particularly important when considering the water turnover events that occur in the spring and autumn of each season in which the thermal stratification of the water bodies influences water movement (McFeters, 1990). Also, storm events can influence the microbiological quality of raw water supplies. The water quality deterioration that occurs after a storm event relates to all land uses over the drainage basin. Storm events typically brings elevations in suspended solids, organic demand materials and organisms to the drainage basin (McFeters, 1990). It is possible that both of these influences were factors during the field trip to the Peace-Athabasca Delta since it was in the autumn and it was raining.

4.2.2.3 Groundwater Samples

During the course of this study there were two groundwater samples analyzed. Fox Lake Well is a wide diameter well. The water from this well is piped about 50 m from the well to the home. Sacred Spring is the other groundwater sample. This sacred spring is located about 35 km from the town of John D'Or and people travel here throughout the year to collect this special water for drinking purposes. Sacred Spring is a good example of the water table/aquifer meeting the surface of the earth and providing a bountiful supply of water. This is an unprotected spring in that the supply of water flowing from the bank is not encased in any man-made structures. From looking at the groundwater results in Table 4-5, it does not appear as though this has had a great influence on the quality of the water obtained even though the water from Sacred Spring is prone to all of the problems associated with surface water supplies since it is not protected. It is interesting to note that the turbidity of the protected covered well is well above the

Table 4-5. Results from Groundwater Analyses.

(a) Physical and Chemical Parameters

Sample	Date	Temp °C	pH	Turbidity NTU	Odour subjective	Conductivity umhos/cm	Colour TCU	Ammonia $mgNH_3$-N/L	TOC mg/L
Sacred Spring	Nov 1 / 94	1.5	7.8	1	musty-bullrush	3400	5	0.012	20.7
Fox Lake Well	Nov 2 / 94	7.5	7.4	13	iron	500	5	0.31	5.4

(b) Metals Analysis

Sample	Date	B ug/L	As ug/L	Ba ug/L	Cd ug/L	Cr ug/L	Cu ug/L	Fe mg/L	Mn ug/L	Pb ug/L	Hg ug/L	Zn ug/L
1993 Canadian Drinking Water Quality Guideline		IMAC 5000	IMAC 25	MAC 1000	MAC 5	MAC 50	AO ≤1000	AO ≤0.3	AO ≤50	MAC 10	MAC 1	AO ≤5000
Sacred Spring	Nov 1 / 9	360	2	43	<1	<1	36	<1	15	<1	2	6
Fox Lake Well	Nov 2 / 9	23	5	160	<1	<1	<1	1.4	210	<1	<1	580

(c) Microbial Parameters

Sample	Date	TC cfu/100mL	FC cfu/100mL	FS cfu/100mL	*Klebsiella* cfu/100mL	Yeasts cfu/100mL	Molds cfu/100mL	48hr HPC cfu/mL	7d HPC cfu/mL
Sacred Spring	Nov 1 / 94	<1	<1	<1	<1	1.8×10^3	3.0×10^2	1.7×10^1	1.7×10^2
Fox Lake Well	Nov 2 / 94	<1	<1	<1	<1	1.0×10^2	3.4×10^2	2.9×10^1	8.9×10^1

GCDWQ limit of 1 NTU. Perhaps this is due to entrapped carbon dioxide air bubbles in the water. This supply should be resampled for turbidity and the air bubbles removed prior to analyzing for turbidity to see if this makes a difference. Also, the aesthetic limits set for iron and manganese were exceeded in this well. At Sacred Spring the mercury level was greater than the MAC of 1 μg/L. This is consistent with the high mercury content observed in the surface water samples collected in the same area.

The ammonia concentration of the Fox Lake well may be a cause for concern. A 1979 survey by the USEPA found that the average total ammonia concentration found in surface waters was 0.18 mg/L and ammonia concentrations in groundwater are usually lower than surface waters because ammonia is generally immobile in soil (USEPA, 1993). Based on this, 0.30 mg/L of ammonia is a relatively high concentration for this ground water well. The source of ammonia in this instance is unknown although it could have been introduced through sewage effluents, industrial effluents or agricultural runoff

(USEPA, 1993). Although ammonia itself does not present an immediate threat to health, nitrate does. Once in a system, ammonia is in a state of constant fluxing of the nitrogen cycle (USEPA, 1993). Processes related to this cycle include ammonification, nitrogen fixation, nitrification, and denitrification (USEPA, 1993). As a result of these processes, nitrifying bacteria proliferate and nitrate can be formed. Nitrate in drinking water can induce methemoglobinemia , particularly in infants, and can also lead to the formation of carcinogenic nitrosamines (AWWA, 1990). Therefore, it would be reasonable to test the well at Fox Lake again to see if the nitrate levels are greater than the MAC of 45 mg/L in the GCDWQ (Federal-Provincial Subcommittee on Drinking Water, 1993).

One further note to make is regarding the very high conductivity that is evident in the groundwater supplies, particularly at Sacred Spring. This can be explained by the fact that groundwater contains more inorganic constituents compared to surface water, because groundwater comes into contact with all types of minerals in the rock strata that surface water never touches (Gabler *et al.*, 1988). The microbial quality of both groundwater samples meets the health related MAC's in the GCDWQ.

4.2.2.4 Snow Water Samples

The results from the snow water samples analyses are presented in Table 4-6. The snow water samples collected near Atikameg contained coliform organisms and therefore do not meet the GCDWQ. The sample that was collected closer to the townsite contained considerably more coliforms than the sample collected farther away in a remote area in the woods. The pH of the snow water is less than that of other surface sources collected in this study. The turbidity of the melted snow samples is 5.24 for the snow closest to the Atikameg townsite and 7.55 for the snow water collected near Twin Lakes. Neither of these turbidity measurements are in compliance with the guideline value of 1 NTU set in the Guidelines for Canadian Drinking Water Quality (Federal-Provincial Subcommittee on Drinking Water, 1993).

Table 4-6. Results from Snow Water Analyses.

(a) Physical and Chemical Parameters

Sample	Date	Temp °C	pH	Turbidity NTU	Odour subjective	Conductivity umhos/cm	Colour TCU	Ammonia $mgNH_3$-N/L	TOC mg/L
Atikameg Snow	Feb 28 / 95	22	6.35	5.24	None	50	65	0.25	4.2
Twin Lakes Snow	Feb 28 / 95	24	6.03	7.55	Rocky	50	45	0.105	3.3

(b) Metals Analysis

Sample	Date	B ug/L	As ug/L	Ba ug/L	Cd ug/L	Cr ug/L	Cu ug/L	Fe mg/L	Mn ug/L	Pb ug/L	Hg ug/L	Zn ug/L
1993 Canadian Drinking Water Quality Guideline		IMAC 5000	IMAC 25	MAC 1000	MAC 5	MAC 50	AO ≤1000	AO ≤0.3	AO ≤50	MAC 10	MAC 1	AO ≤5000
Atikameg Snow	Feb 28 / 9	<1	<1	1	1	<1	<1	10	6	1	<1	6
Twin Lakes Snow	Feb 28 / 9	<1	<1	<1	<1	<1	<1	9	8	<1	<1	<1

(c) Microbial Parameters

Sample	Date	TC cfu/100mL	FC cfu/100mL	FS cfu/100mL	*Klebsiella* cfu/100mL	Yeasts cfu/100mL	Molds cfu/100mL	48hr HPC cfu/mL	7d HPC cfu/mL
Atikameg Snow	Feb 28/95	5.8×10^2	<1	<1	<1	4.1×10^3	2.8×10^3	1.2×10^2	1.5×10^2
Twin Lakes Snow	Feb 28/95	1.0×10^0	<1	<1	<1	4.6×10^3	4.6×10^3	1.3×10^2	1.2×10^2

4.2.2.5 Bottled Water Samples

There were two types of bottled water sampled. Both were purchased at a store in Atikameg on February 28, 1995. The Bottled Ozonated Water was stored in the refrigerator in a 2 L plastic container. The Bottled Spring Water came from High Prairie, Alberta and was stored on the floor of the store in 16 L plastic containers. These bottled waters meet the guidelines for both turbidity and coliform concentration. But, it should be noted that the HPC counts for both brands of bottled water are extremely high. As discussed earlier, some of the bacteria in HPC counts may be opportunistic pathogens. This could have serious implications for people with decreased immunity including the very young, the very old, immunocompromised individuals and the sick. The high levels of general bacteria found in the bottled samples is consistent

with the findings from other studies. The results from the bottled water analyses is presented in Table 4-7.

Table 4-7. Results from Bottled Water Analyses.

(a) Physical and Chemical Parameters

Sample	**Date**	**Temp** °C	**pH**	**Turbidity** NTU	**Odour** subjective	**Conductivity** umhos/cm	**Colour** TCU	**Ammonia** $mgNH_3$-N/L	**TOC** mg/L
Bottled Ozonated Water	Feb 28/95	4	6.47	0.21	sweet "rain"	150	33	0.01	1.22
Bottled Spring Water	Feb 28/95	17	6.33	0.13	plastic/ none	30	30	0.01	0.67

(b) Metals Analysis

Sample	**Date**	**B** ug/L	**As** ug/L	**Ba** ug/L	**Cd** ug/L	**Cr** ug/L	**Cu** ug/L	**Fe** mg/L	**Mn** ug/L	**Pb** ug/L	**Hg** ug/L	**Zn** ug/L
1993 Canadian Drinking Water Quality Guideline		IMAC 5000	IMAC 25	MAC 1000	MAC 5	MAC 50	AO ≤1000	AO ≤0.3	AO ≤50	MAC 10	MAC 1	AO ≤5000
Bottled Ozonated Water	Feb 28/95	<1	<1	6	<1	<1	<1	7	4	<1	<1	<1
Bottled Spring Water	Feb 28/95	<1	<1	<1	<1	<1	<1	11	4	<1	<1	<1

(c) Microbial Parameters

Sample	**Date**	**TC** cfu/100mL	**FC** cfu/100mL	**FS** cfu/100mL	**Klebsiella** cfu/100mL	**Yeasts** cfu/100mL	**Molds** cfu/100mL	**48hr HPC** cfu/mL	**7d HPC** cfu/mL
Bottled Ozonated Water	Feb 28/95	<1	<1	<1	<1	<1	<1	8.9×10^2	5.6×10^3
Bottled Spring Water	Feb 28/95	<1	<1	<1	<1	3.9×10^4	2.0×10^3	1.7×10^3	4.6×10^3

4.2.2.6 Trihalomethane Formation Potential Analyses

Table 4-8 tabulates the results of the Trihalomethane Formation Potential (THM-FP) analyses performed on raw water samples from the first two field trips. Essentially, THM-FP involves dosing a 250 mL water sample with an excessive quantity of chlorine so that all of the trihalomethane precursors in the water sample will react with chlorine and the maximum concentration of trihalomethanes can be formed without being limited by free available chlorine. Unfortunately, the chlorine dose used in the experiments was insufficient and there was no free chlorine residual after the 7 day reaction period.

Table 4-8. THM Formation Potential Analysis.

Location	TOC (mg/L)	Chloroform (µg/L)			Bromodichloro-methane (µg/L)			Dibromochloro-methane (µg/L)			Bromoform (µg/L)		
	RAW	RAW	3:1	6:1	RAW	3:1	6:1	RAW	3:1	6:1	RAW	3:1	6:1
Old Fort	6.7	6	570	650	1.3	22	28	BDL	0.6	1.6	BDL	1.1	0.2
Keane River	5.0	14	310	-	BDL	38	-	BDL	3.1	-	BDL	0.3	-
Jackfish Village	5.9	4	503	-	BDL	13	-	BDL	0.2	-	BDL	1.4	-
Prairie River	19.7	4	1414	-	0.6	74	-	BDL	4.8	-	BDL	0.2	-
Quatre Forches	5.6	7	440	541	BDL	14	16	BDL	1.0	1.1	BDL	BDL	BDL
Lawrence Creek	29.0	7	1770	-	6.2	210	-	0.2	28.0	-	BDL	1.3	-
Lawrence River	15.7	4	1372	-	1.4	26	-	BDL	0.2	-	BDL	0.2	-
Birch Creek	11.4	3	879	-	1.4	67	-	BDL	3.5	-	BDL	0.2	-
Sacred Spring	20.7	2	1237	-	1.6	202	-	BDL	46.0	-	BDL	2.4	-
Little Red River	23.2	5	2383	2837	1.9	25	27	BDL	0.6	0.9	BDL	0.3	0.4
Fox Lake Well	5.4	3	129	-	BDL	8	-	BDL	2.0	-	BDL	BDL	-
John D'Or Cistern	10.7	108	722	-	5.5	15	-	BDL	1.3	-	BDL	0.1	-
Wentzel River	17.3	1	1492	1707	2.8	35	40	BDL	0.8	0.3	BDL	0.2	0.3

Notes:

1. The 3:1 and 6:1 headings are the Chlorine:TOC ratios used for chlorine dosing of the samples.
2. BDL = Below Detection Limit
3. For the Chlorine Dose, initially, a Chlorine:TOC ratio of 3:1 was used as was suggested in the literature. However, after the 7-day reaction period required for THM Potential analyses, there was no residual free chlorine left in the sample. Therefore, it was decided to try the same experiment a second time with a Chlorine:TOC ratio of 6:1 for four of the samples. Once again, there was no residual chlorine left at the completion of the seven day reaction period, so the results are not completely accurate. Nonetheless, trends in the THM potential analysis are evident and therefore, the results can still be interpreted.

The Trihalomethane concentration found in the raw water samples was well below the GCDWQ limit of 100μg/L. This limit was exceeded in the treated water sample at John D'Or Prairie. Also, it is interesting to note that chloroform is typically the largest component of the trihalomethane concentration followed by bromodichloromethane, dibromochloromethane and bromoform. However, larger amounts of brominated compounds, relative to chloroform indicate a higher concentration of dissolved bromide in the water (APHA *et al.*, 1992). This was the case for Wentzel River. None of the raw water samples contained bromoform. The existence of chloroform in the raw water samples was very small and may be a result of contaminated reagents or glassware.

The THM concentrations are very high after both the 3:1 and the 6:1 Chlorine:TOC dosing. The 3:1 dosing ratio was obtained from prior THM-FP analyses performed at the University of Alberta Environmental laboratory. After the first experiment was complete and it was found that there was not any chlorine residual left over, it was decided to re-run some of the same samples at the 6:1 dose. This dose was still inadequate to provide for an excess free chlorine residual, but trends in the data can be analyzed nonetheless. The potential formation of trihalomethanes certainly seems to be correlated with the Total Organic Carbon concentration. The higher the TOC, the more potential that sample has to form trihalomethanes if chlorine is added. Chloroform is in the highest concentration followed by successive brominations in the order of bromodichloromethane, dibromochloromethane, and bromoform. The concentrations of detectable trihalomethanes were higher after the 6:1 chlorine dose than after the 3:1 chlorine dose. The very large chlorine demand exhibited by these samples and the subsequent formation of large quantities of trihalomethanes suggest that raw water in the study area should be filtered prior to disinfection. By filtering the supply, some of the organic THM-precursors would be removed and consequently the formation of disinfection-by-products would decrease.

4.3 Discussion

4.3.1 Assessment of Water Samples Analyzed

There were 20 samples of non-conventional sources of drinking water collected during the course of this study. This included samples of: (1) raw surface water from lakes, rivers and creeks; (2) groundwater from an unprotected spring and a protected well; (3) snow water; (4) bottled water; (5) point-of-use treated water; and (6) conventionally treated water (for comparative purposes). Unfortunately, samples of other sources of non-conventional drinking water were not obtained such as water from a dugout, rain water, or birch tree water. Nonetheless, the samples that have been collected and analyzed to date represent the start of a database on the physical, chemical and microbiological quality of some non-conventional sources of drinking water.

The conventionally treated drinking water provided the highest quality of drinking water because it met the health related guidelines in GCDWQ. Microbiologically the groundwater samples collected were of good quality. However, some of the limits in the GCDWQ were exceeded. The bottled water sampled m*et all* of the health related guidelines regulated in Canada. However, the HPC's were very high in both samples, some of which could be opportunistic pathogens. The level of yeasts and molds was also very high for the bottled water that was being stored at room temperature. Untreated surface water does not meet many of the health related guidelines in GCDWQ. Turbidity is greater than 1 NTU in all of the surface water samples. All of the samples had total coliform organisms. From this, it can be concluded that surface water must be treated prior to consumption.

It should be noted, that the sampling itself provided an insight into the methods of non-conventional drinking water collection Sometimes, long distances were travelled to areas where people would collect "special" drinking water. Other times, this involved trekking through the wilderness to an appropriate place away from human activity. However,

there are some limitations that should be discussed with reference to the sampling portion of this study. Many of the samples that were collected were raw water sources that local residents said were used for drinking water purposes. In some cases (particularly with the raw surface sources) these were not samples of actual water being consumed by individuals at the time of collection. Furthermore, for each site sampled, 4.25 L of water were collected for analysis. When the supply of drinking water is limited, such as at the remote camp on Prairie River where the residents hauled water in 20 litre containers, 4.25 L is a large amount of water.

Scientific research based on laboratory derived results is not without its limitations. This can be highlighted by discussing the inherent problems associated with the microbiological analysis of water supplies. Results of routine microbial sampling should be interpreted with the awareness that each result is liable to two sorts of error, even if proper protocol is followed. First, there is sampling error because there is a variation in microbial density in different parts of the water being sampled. Second, there are many statistical inaccuracies that may be introduced by laboratory methods (Tillett, 1993).

4.3.2 Assessment of Interviewing Component

Social scientific research involves studying people and aims to determine logical and persistent patterns of regularity in social life (Babbie, 1992). Since people are dynamic and changing, social research is an "open-ended enterprise in which conclusions are constantly being modified (Babbie, 1992)." The practice of social scientific research itself has many limitations and as Babbie (1992) points out, there are many errors involved in personal human inquiry such as:

1. inaccurate observation;
2. overgeneralization;
3. selective observation;

4. made-up information to explain away confusion and contradictions;
5. illogical reasoning;
6. ego involvement on behalf of the researcher;
7. premature closure of inquiry;
8. mystification (attributing supernatural causes to phenomenon that are not understood); and
9. human error.

These sources of error should be considered when interpreting a social scientific research report of any sort. This one is no exception.

One of the main limitations with the social scientific investigation was the limited number of people in the study area interviewed. Linked to this was the method for getting interviews. As mentioned earlier, prospective interviewees were obtained by "snowball sampling". For the most part though, the majority of the interviews were obtained with the help of the community guide and were with the people that he or she knew which restricted the interviewer at the onset. Therefore, the sample is not random and hence it is a selective group of people in which this person knows that person and so on and so on. Therefore, the sample population is not representative of the larger population as a whole. Because of the limited sample size and the method of obtaining interviewees, the results reflect the individual responses of people interviewed and do not necessarily reflect the attitudes and practices of all residents in the study area. In other words, surveys such as this one "cannot measure social action; they can only collect self-reports of recalled past actions of prospective or hypothetical actions (Babbie, 1992)." However, this aspect of the thesis can provide some background information for future studies regarding non-conventional drinking water practices and supplies.

The actual interview was also a limiting factor in some ways. During the first field trip it did not always seem suitable to pull out the piece of paper with the questions on them and ask them word for word. Rather, the interviewing sessions followed an informal format

with all of the areas of interest covered. For the most part, the people being interviewed were just sharing their thoughts about drinking water quality and health, non-conventional/traditional methods of drinking water collection, treatment and consumption. Since the interviews were just one aspect of a much larger exploratory study, the informal discussion-like interviews were satisfactory for the purposes of this report. Perhaps future studies in the area of non-conventional drinking water practices could be structured within a matched case-control epidemiological study using health record data as the case-control criterion.

The assessment of non-conventional drinking water in the Northern River Basins certainly has a traditional and perhaps a cultural component to it. Therefore, in approaching this study, the focus was not to find a reason to undermine traditional ways, rather, it was to try to gain an understanding about them. Unfortunately, as a university researcher, and an outsider, there were many barriers involved in communicating this intent. First, in some of the areas visited, Cree was the primary spoken language. Unfortunately the author of this thesis can not speak Cree and there will always be some meaning lost in translations. Second, people seemed suspicious of the motives behind collecting samples. One of the field guides explained that many people would not be willing to share their knowledge for fear that they would be told that they could no longer do what they were doing. For instance, one person interviewed from John D'Or Prairie, told someone that he hoped that I would not tell him that he could not drink his "special water" anymore. Hugh Brody (1988) had a similar experience in his study in a North American Indian community. Brody summed the sentiments of the people he was dealing with by saying "it is never easy to know why research is being done, or whose interests in the end will be served." Another limitation to this data collection regarding non-conventional drinking water practices was the relatively short amount of time spent in the communities. To obtain a full understanding of some of the traditional ways of obtaining water, more time should be spent in the communities to get to know the residents, to gain their trust, and to actually participate in the activities that are being studied. For example, this may include taking part in a living-off-the-land expedition such as trapping. In this way, the actual

method of collecting snow or ice for drinking water can be observed and maybe other aspects will be revealed that would not be observed otherwise. Another alternative may be to have the CHR's become more active researchers in a study of this nature in the future.

Some of the traditional views on what water means to the people was learned as a result of the social science research component of this study. Lea Bill (1994), one of the Traditional Knowledge Component leaders, had some words of wisdom regarding the native perspective on water as described in the following excerpt:

> In the native view of life, everything has a spirit and all spirits must be treated with respect. The Water Spirit has not always been treated with the respect it deserves and therefore the spirituality of the water has changed. This is because people have put things into the water that have changed the Water Spirit. Also, the water flows in a certain way in a cleansing process. When water becomes diverted it will not necessarily cleanse itself the same way. The Grandfathers also had some messages that were passed on through Ms. Bill. First, the grandfathers suggested that researchers "Look deeper." To do this, the ions, ionization energies, and the electricity of the water should be investigated. The Grandfathers also said to "look at the ions and how they interact with the water molecule." And the final message was to "consider the nutrients of the waters."

Interpretation and assessment of these concepts using normal scientific techniques is uncertain and difficult at best. Understanding all of the relationships between drinking water quality, health and personal beliefs is far from being known in a scientific sense. However, it has long been known that the perception is important in a person's assessment of drinking water quality.

One of the objectives of this thesis was to suggest a series of population sub-groups that may be particularly pre-disposed to using a non-conventional source of drinking water. It has been inferred from the people talked to in this study that elderly residents in the study area may be more likely to consume a non-conventional source of drinking water. This

could be because this was their traditional way and it is what they are used to. During the course of the research there was talk of several elderly residents that would collect "*special drinking water*" even if they had conventionally treated drinking water coming to their home. Another population sub-group that is certainly predisposed to utilizing non-conventional sources of drinking water are those that live in isolated and remote areas in the Northern River Basins. This is logical because conventionally treated drinking water is not accessible in all areas. A third population sub-group includes individuals that live off the land. This group is not only comprised of aboriginal people that live partake in traditional living off the land activities such as hunting, fishing, trapping and gathering, but also wilderness campers that camp in NRBS areas.

Therefore, providing a safe supply of drinking water involves the utilization of an appropriate technology. This implies that the water supply system will be utilized, maintained and operated by those it serves (Okun, 1988). Appropriate technology begins with the involvement of the people affected in the decisions made. Drinking water treatment for elderly residents, people living off the land, and for people living in remote areas in the NRBS must be appropriate, taking into account local conditions, culture, economy and sociology.

5. PORTABLE FILTER ASSESSMENT

5.1 Portable Filters on the Market in the Edmonton area

Currently, there are a wide variety of portable water filtration units on the market. The filters are typically hand held units that are pumped to force the water through the media, although gravity fed units and suction straw-type devices are also available. The filter media is either permanently encased in the units or else it comes in replaceable cartridges. There are many types of media utilized in these units including activated carbon, polyethylene, iodinated resins, silver impregnated ceramic, pleated paper, and proprietary materials. Proprietary materials means that the manufacturers will not disclose the ingredients of the active agents to protect the formula from being used by other manufacturers. Initially a survey of camping and wilderness stores in the Edmonton area was completed to find out what types of portable filters were available. The types of units found during this survey, along with some of the manufacturers claims about these units, are presented in Table 5-1. The information in this table was gathered by: (1) visits to Edmonton retail stores; (2) contacting the manufacturers of each of the units and by referring to instruction manuals included with the filters; (3) consulting *wilderness activity* publications that had compiled information on portable drinking water treatment filters.

The prices shown in Table 5-1 are approximate Canadian dollars at the time of the survey and were obtained by taking the average price of the unit in all Edmonton stores surveyed. Each unit was then ranked according to cost. First, all of the units were ranked based on the initial cost to the buyer, from the cheapest to the most expensive. Then, the units were ranked based on the cost per 1000L and also based on the cost per 10000L. From this ranking, it is apparent that more than just the initial cost should be considered when purchasing a treatment device. For example, by looking at Filter #10, it is one of the least expensive units to buy based on the initial price, but the most

Table 5-1. Types of Portable Drinking Water Treatment Filters Available At Edmonton Retail Stores.

Filter Media	Type of Filter	Absolute Pore Size(μ)	Output (L/min)	Weight (g)	Capacity per cartridge (L)	Cartridge Price ($)	Unit Price ($)	Rank by Initial Cost	$/1000L	Rank by $/1000L	$/10000L	Rank by $/10000L
Carbon	Pump	0.4	0.88	425	378	50	90	10	190	11	1390	13
Carbon	Pump	0.5	0.57	198	45	16	50	3	402	17	3602	16
Carbon	Pump	0.3	1.14	312	757	40	80	8	120	5	600	7
Carbon & Surface Filter	Pump	0.02	1.19	510	94	21	130	12	340	15	2356	15
Carbon & Surface Filter	Pump	0.5	1.14	312	800	38	58	5	96	2	514	6
Carbon & Ceramic	Gravity	0.9	0.28	680	3785	60	100	11	100	3	220	1
Silver Impregnated Ceramic	Pump	0.2	0.4	227	3785	85	170	14	170	8	340	3
Silver Impregnated Ceramic	Pump	0.2	0.74	652	15141	134	300	16	300	14	300	2
Ceramic & Surface	Pump	0.02	0.85	510	378+	28	150	13	206	12	878	9
Iodinated Resin	Pump	N/A	0.28	57	50	NR	35	1	700	19	7000	19
Iodinated Resin	Pump	N/A	0.4	170	200	45	70	6	250	13	2275	14
Iodinated Resin	Pump	1	1.7	567	2000	60	180	15	180	10	420	4
Iodinated Resin	Pump	1	1.14	340	750	54	85	9	139	6	787	8
Iodinated Resin	Pump	1	0.57	340	400	45	85	9	175	9	1165	12
Iodinated Resin	Gravity	N/A	0.28	170	378	NR	37	2	111	4	999	11
Iodinated Resin	Gravity	N/A	0.57	567	94 to 378	40	57	4	457	18	4297	18
Iodinated Resin	Straw	N/A	Unknown	Unknown	95	NR	35	1	385	16	3710	17
Polyethylene	Pump or Straw	2[1]	0.75	Unknown	378	17	35	1	69	1	477	5
Unknown	Gravity	Unknown	Unknown	450	900	NR	75	7	150	7	900	10

Notes: (1) This is a nominal pore size rating. An absolute rating was not available.
(2) Abbreviations: **N/A** = Not Applicable or Not Available. **Unknown** = Information not found by the authors of this report. **NR** = Not Replaceable
(3) References: Adapted from Getchell, 1994; Alvarez and Hodgson, 1994; personal communication with manufacturers; and instruction manuals included with the filters.

expensive to buy if large volumes of water are to be filtered. This is due to the extremely low capacity of the unit. The design of the unit is also important to consider when choosing a device to buy. The gravity type filters are typically larger and more cumbersome and filtering takes longer. Probably the most important factor when purchasing a portable point-of-use water treatment filter is whether or not these units produce a good quality of water. The pore size ratings should give some indication of the effectiveness of removal of microorganisms and other particles in the water. The pore size is the size of the openings in the filter element. An absolute rating means that the filter will not pass any particles below the given size, whereas a nominal pore size rating indicates that "most" particles above the given size are removed (Getchell, 1994). According to Getchell (1994) a pore size rating of 0.2μ is required to filter out bacteria, a pore size of 4μ is required to filter out protozoa, such as *Giardia* and *Cryptosporidium*, and a pore size of 0.0004μ is necessary to filter out viruses. Due to the small pore size required to filter out viruses, there are not any filters that can effectively remove viruses by occlusion alone. However, some of the units have iodine in them, which may act as a disinfectant to kill viruses.

After researching the various types of filters on the market, it was decided to further investigate the effectiveness of some of these filters to determine if they would be suitable for people in the study area that live off of the land. This investigation was felt necessary because little scientific information was available to assess their performance. Given that the results from the sampling program indicated that some form of treatment was required in most cases, particularly if the water was obtained from a surface source, a testing program was undertaken to determine if these filters were viable options for living off the land expeditions. This assessment was done by laboratory testing of selected units under worst case conditions and is described below.

5.2 Experimental Methodology

5.2.1 Portable Filter Selection

The first step was to select suitable filters for testing. There were several factors involved in the decision making process. In Table 5-1 it can be seen that there are four general types of filter media used in these portable treatment devices: (1) activated carbon, (2) ceramic, (3) iodinated resins, and (4) polyethylene. Initially, it was thought that one unit would be chosen for analysis from each type of filter media. However, after further research, it was decided that for this project, the assessment of the units containing iodine was unnecessary. There were three main reasons governing this decision. First and foremost, it appears that many of the residents of Northern Alberta that tend to be involved in living off the land activities, have not acquired a liking for the taste of chlorine in their drinking water. If they have not acquired a taste for chlorine, then it is not likely that they will find the flavour of iodine pleasing. Second, as outlined in Protocols for Point-of-Use Devices Guide Standard and Protocol for Testing Microbiological Water Purifiers (USEPA, 1987), non-purifying units that rely primarily on occlusion can be tested using 4 μ to 6 μ particles instead of live *Giardia* organisms. Third, worst case conditions for units containing iodine are different than for units that do not contain iodine. That is, the worst case challenge for iodinated units involves using a test water with a low pH whereas non-iodinated units are challenged by high pH waters.

Three different types of filters were chosen for further laboratory analysis. These filters were chosen to represent the larger industry as a whole. One of the most expensive ones on the market, the least expensive one available and a mid-price-range filter were chosen. Each is from a different manufacturer. Each unit has a different type of media with which it filters the water. From Table 5-1 the filters chosen for testing were the ones labelled 5, 7 and 18. For the purpose of this report, these units will be called "Carbon", "Ceramic" and "Plastic" respectively.

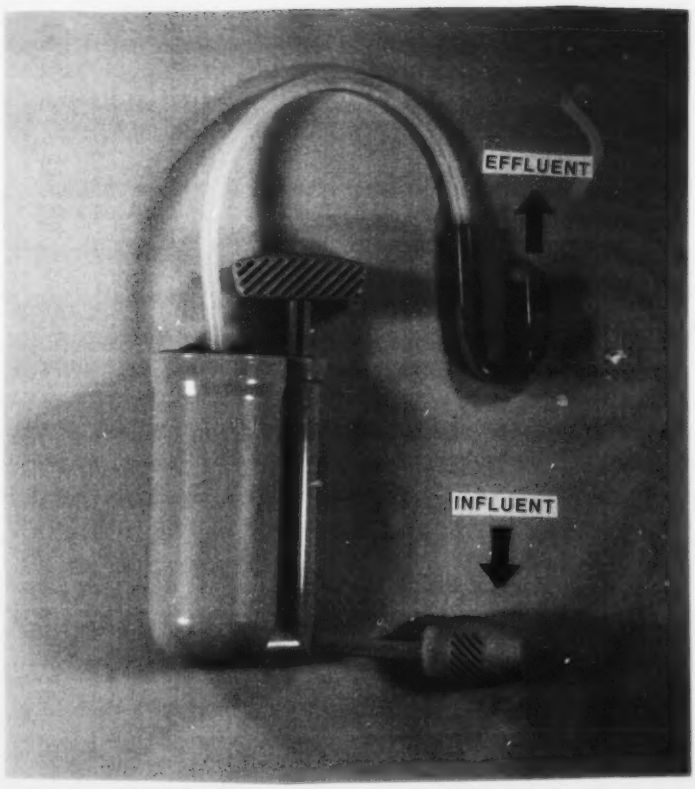


Figure 5-1. Carbon Portable Drinking Water Treatment Filter

The Carbon filter is illustrated in Figure 5-1. The flow of water through this unit is first through a preliminary foam pre-filter that filters out larger particles before entering the main body of the filter. Once inside the body of the filter, the water passes through a pleated paper filter that surrounds an activated carbon core. After passing through the activated carbon, the water is pumped through an effluent hose and can be collected. The pumping rate for this filter is recommended to be between 20 and 30 strokes per minute.

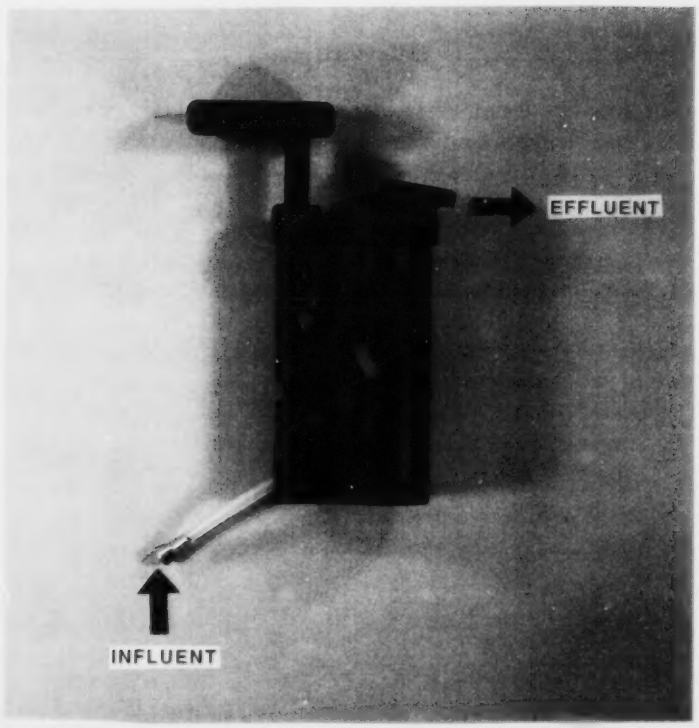


Figure 5-2. Ceramic Portable Drinking Water Treatment Filter

Figure 5-2 contains a picture of the Ceramic filter. The pre-filter for this unit is stainless steel. Water is pumped through a 0.2μ silver impregnated ceramic filter in the body of the unit before it passes through a small outlet at the top of the filter. There is no effluent hose associated with this unit. This ceramic filter comes with a "regeneration brush" that is to be used to scrape the surface of the filter when pumping has become noticeably more difficult indicating that the filter pores have been blocked. This regeneration brush has an associated gauge that is to be used to check the diameter of the ceramic. Once the diameter of the filter fits within the gauge area, the filter is exhausted and a new filter cartridge is required.

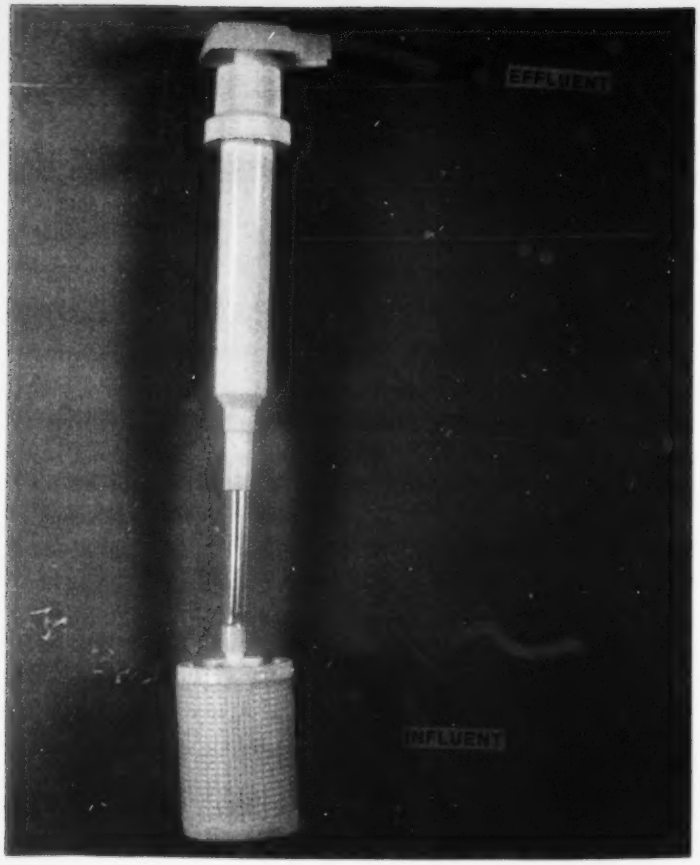


Figure 5-3. Plastic Portable Drinking Water Treatment Filter

Figure 5-3 is a picture of the Plastic filter chosen for analysis. The water flows directly through the polyethylene matrix filter body without any pre-filtering. Unlike the Ceramic and Carbon devices, the filter element associated with the Plastic unit is not enclosed in a casing. The effluent can be collected in two ways with this unit. The first method of collection is by attaching a hose to the opening in the pump handle and pumping the water into a collection flask. Alternatively, the water can be sucked out by using a straw attachment instead of the pump. For the laboratory analysis, the pumping method was used for collecting the effluent.

5.2.2 Preparation of the Challenge Test Water

It was decided to test these three filters under worst case conditions that could possibly occur in the study area. To do this, a suitable challenge water had to be developed. Due to the large volume of water that was to be filtered, it was not feasible to use actual water samples from the study area. Furthermore, it was also important for comparison purposes that the water tested be of consistent quality. Therefore, a challenge test water was created under controlled laboratory conditions to try to represent a worst case scenario that could be expected in Northern Alberta. To determine the levels of the parameters in the test water, raw surface water data from the area was analyzed. This data came from samples taken in the Treated Water Survey (Prince *et al.*, 1994) and from samples taken on field trips during the course of this study. Based on this raw water data and on literature on other challenge waters made, the test water was created to have the characteristics listed in Table 5-2.

Table 5-2. Challenge Test Water Characteristics

Parameter	Challenge Level	Ingredient	Amount of Ingredient Added for Challenge
Water		Distilled Water	75 L
E. coli challenge	10^6 cfu/100mL	Pure culture *E. coli* (ATCC 13706) suspension	c.a. 9 mL of 24 hour suspension (i.e. 1 mL of *E. coli* incubated in 10 mL of media for 24 hours)
Total Organic Carbon	20 mg/L	Humic Acid and Glucose	Humic Acid: c.a. 260 mL of 1.5 g/L suspension. Glucose: 3.75 g
Total Dissolved Solids	180 mg/L	Sodium Chloride (NaCl)	11.25 g NaCl
pH	8.0	NaOH or HCl	c.a. 1 mL NaOH
Turbidity	30 NTU	S.A.E. Fine Test Dust	2.0 g S.A.E. Test Dust
Particle Sizes	Ranging from 1 μ to >50 μ	S.A.E. Fine Test Dust	(included with above)

The USEPA's document entitled Protocols for Point-of-Use Devices Guide Standard and Protocol for Testing Microbiological Water Purifiers was consulted for ingredients to use to simulate this challenge water (USEPA, 1987). The appropriate amounts of each ingredient to be added was determined through preliminary laboratory testing. The test water was prepared in a 120L container each day of the actual experiment. After all of the ingredients were added, the test water was left to mix at 600 rpm for approximately one hour so that the bacteria had time to acclimatize to the new conditions. The mixing continued for the duration of the filtering to keep all of the ingredients in suspension.

5.2.2.1 E. coli Suspension Preparation

A 1 mL pure suspension of *E. coli* (ATCC 13706) was incubated at 35°C for 24 hours in 9 mL of sterile tryptic soy agar (TSA) liquid agar overnight. Each day 1 mL of the suspension was transferred to 9 mL of sterile TSA agar so that the microorganisms were kept in the exponential growth phase for the challenge test water.

5.2.3 Experimental Design

The basic experimental design used to evaluate these filters was a two way analysis of variance (ANOVA); with filter types as the "treatment" variable, and microbial reduction, particle reduction and turbidity reduction as the "effect" variables. Both the treatment and effects were analyzed in triplicate. A design such as this one allows for comparing "between" and "within" treatments (Box *et al.*, 1978). In other words, the difference between the different types of filters (i.e. Carbon vs Ceramic vs Plastic) can be analyzed, as well as the difference within each triplicate of filter type (i.e. Carbon Filter 1 vs Carbon Filter 2 vs Carbon Filter 3). Once all the data was collected, it was assessed using analysis of variance tables like those described by Box *et al.*, (1978).

Analysis of the data was performed using the statistical programming features of Microsoft Excel 6.0. ANOVA tables were generated on the percent reduction data for the averages obtained. The results of these analyses are discussed in Section 5.3.

5.2.3.1 Filter Conditioning

Three prototype water filters of each brand were set up and conditioned according to manufacturers instructions prior to starting the tests. This involved filtering 1 L of water through the Carbon unit, filtering water through the Ceramic unit until it was "optically clear", and nothing for the Plastic filter. To keep the filtered volumes uniform, 1 L of distilled water was filtered through each unit prior to the onset of the challenge testing. It should be noted that this 1 L conditioning is not included in the total volume filtered in the results discussed later in this report.

5.2.3.2 Apparatus

The apparatus used in the experiment is illustrated in Figure 5-4. The three triplicate filters were mounted upright with metal strappings onto a piece of wood. The handles of each filter unit were attached to another piece of wood using hose clamps and screws so that each unit could be pumped uniformly. The boards were attached to the side of a laboratory bench using C-clamps during the pumping cycles.

The influent challenge test water was prepared in 75 L volumes in a 120 L cylindrical container as described above. This challenge water was stirred at a rate of approximately 600 rpm for the duration of the experiment. The influent hoses were

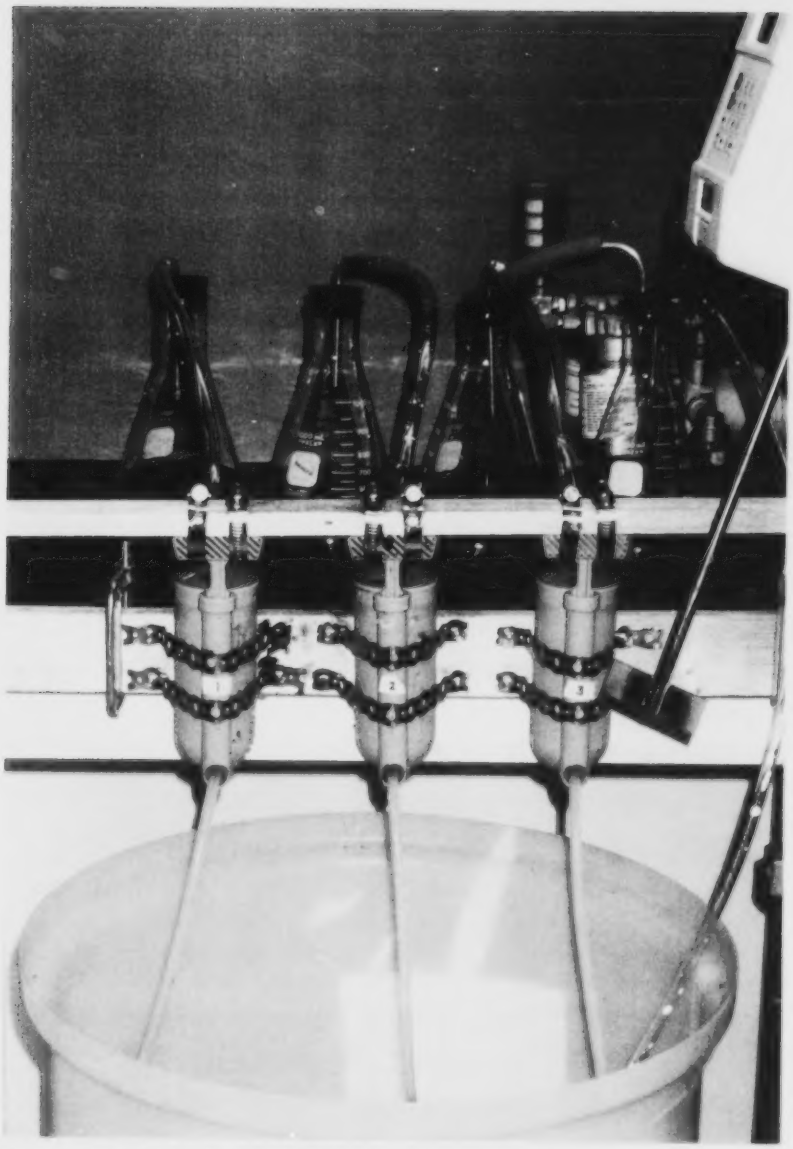


Figure 5-4 Experimental Apparatus

Figure 5-5. Challenge Test Water with Velcro Hose Attachments

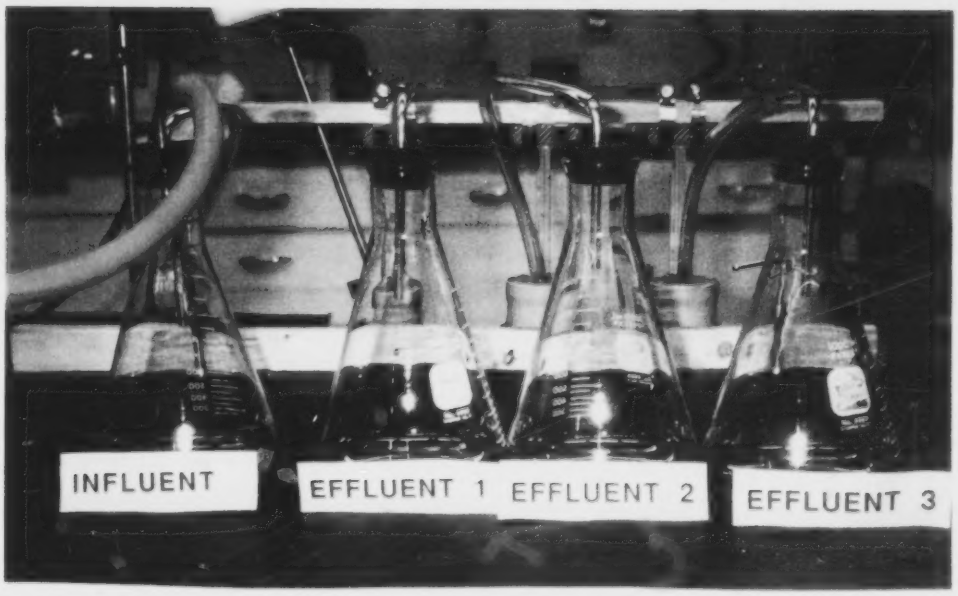


Figure 5-6. Influent and Effluent Collection Flasks

fastened to the side of this tank with velcro (as shown in Figure 5-5) so that they would not get strangled in the mixer.

The units were pumped manually at the rate specified by the manufacturers. Since the handles of each of the triplicate filters were attached to a wooden crossbar, they could all be pumped in unison so that differences in pumping pressure and rate would be limited.

Influent and effluent water samples were collected in 1 L sterilized Erlenmeyer flasks as shown in Figure 5-6. At the onset of each experimental day, a pre-determined volume was set to be filtered. Influent and effluent samples were taken at 1 L, 4 L, 6 L, 8 L, 10 L and 20 L.

5.2.3.3 Analytical Procedures

The influent and effluent samples were analyzed for *E. coli* concentration, particle counts and turbidity for each filter.

Microbial Analysis

The microbial analysis done on influent and effluent samples consisted of enumerating *E. coli* organisms. *E. coli* was chosen as a bacterial indicator organism because of its known presence in contaminated raw water supplies and because it is a member of the coliform group of bacteria that are regulated in the GCDWQ.

The samples for the microbial assays were collected in sterile flasks. The analytical membrane filtration procedure followed was the same as for the Total Coliform analysis done on non-conventional water samples. There was one variation though that involved neutralizing the silver in the samples collected from the ceramic units. 10 mL of Chamber's solution (7.3% sodium thiosulphate and 5% sodium thioglycolate) was added

per litre of sample collected from the ceramic units (USEPA, 1987; Environmental Health Directorate, 1980).

Viruses are another microbial pathogen of interest in the assessment of drinking water treatment technologies. Viruses were not included in this protocol for assessing portable drinking water treatment filters for a couple of reasons. First, assaying viruses is a time consuming, difficult and costly procedure (Emde, 1995). Second, viruses are generally 10 nm to 25 nm particles (AWWA, 1990) so they will not be removed by occlusion filtration alone. Since both the plastic and carbon filters rely on occlusion filtration, it is deduced that these two filters will not remove viruses. The ceramic filter is impregnated with silver which purportedly has some disinfection capabilities. However, because this was an exploratory study, viruses were not chosen for microbial assessment of the water filters.

Protozoans are also pathogenic agents of concern in drinking water. *Giardia* and *Cryptosporidium* are of particular relevance in untreated surface waters as may be found in Northern Alberta. Therefore, an assessment of the filters performance in removing these protozoans would be valuable. However, there are some difficulties associated with cyst production and measurement technologies with these organisms (USEPA, 1987). Therefore, since these filters rely primarily on occlusion filtration, it is feasible to test the units using glass spheres or particles from automotive test dust (USEPA, 1987). The utilization of these particles as representatives of *Giardia*, *Cryptosporidium* and bacteria is explained below in the section on particle counting.

Particle Counting

The particles were counted using a Hiac/Royco HRLD-150 Particle Analyzer. This is a multiple channel, vacuum based batch sampler with a light obscuring sensor. In this type of instrument, a light beam of known intensity shines through a defined "sensing zone"

within the sensor (Lewis *et al*, 1992). Particles are then sized based on the decrease in light intensity and comparing the results with previously calibrated standards.

The Hiac/Royco HRLD-150 is capable of measuring particles 1.0 μ to 150 μ in diameter in eight particle size range channels. When using a multiple channel counter like this one, it is best to choose narrower channel widths for smaller particle sizes (where particles are most numerous) and wider channel sizes for larger particle sizes (where fewer particles will be detected) (Lewis *et al*, 1992). With this in mind, the channels were set to count particles in the following ranges: (1) 1 μ to 2 μ; (2) 2 μ to 3 μ; (3) 3 μ to 4 μ; (4) 4 μ to 5 μ; (5) 5 μ to 10 μ; (6) 10 μ to 25 μ; (7) 25 μ to 50 μ; and (8) 50 μ to 150 μ. These particle size ranges were also chosen to try to assess filter performance of removing a few target organisms such as *Giardia*, *Cryptosporidium* and bacteria. Bacteria range in size from 0.125 μ to 28 μ (Singleton and Sainsbury, 1981) but the size range for most bacteria is 0.3 μ to 1.0 μ (Smith, 1994). Hence, the smallest range of 1 to 2 microns will be used to analyze for bacterial removal abilities. For *Giardia*, the 5 to 10 micron size range will be used to assess for potential *Giardia* reduction. This size range was chosen based on the dimensions given by LeChevallier and Norton, (1992) and the AWWA (1990) which were 9 μ x 12 μ and 6 μ x 10 μ (cyst form) respectively. Therefore, particle reduction in the 5 to 10 micron range should give some indication of *Giardia* removal. The other protozoan of interest was *Cryptosporidium* which averages 4.7 μ in diameter (LeChevallier and Norton, 1992). Therefore, assessing particle reduction in the 4 to 5 micron range should be indicative of *Cryptosporidium* removal. The assessment of larger particle reduction was done by looking at the results from the 10 to 25 micron particle counts.

Influent and effluent grab samples were analyzed in triplicate in 10 mL volumes at a flow rate of 25 mL/min by the particle counter. The concentration limit for this instrument was 18 000 particles per mL. Therefore, if this limit was exceeded, the results were invalid (Lewis *et al*, 1992) and the samples had to be diluted with Milli-Q water and re-analyzed until the total number of particles was within this countable range. The results presented

in the following section of this thesis have been corrected for any dilutions and also for the particles contributed by the Milli-Q water added. Since all of the surfaces that come into contact with the sample may contribute particles (Lewis *et al*, 1992), care was taken to thoroughly rinse all sample and dilution bottles with Milli-Q water prior to analysis.

Turbidity Analysis

Influent and effluent turbidity was measured using a portable digital Hach turbidimeter that was calibrated using prepared formazin standards. Both the (bacteria) level and particle counts are correlated to turbidity (LeChevallier and Norton, 1992). Therefore, it is expected that a reduction in turbidity will be associated with a reduction in particle and microbial levels. The advantage of assessing turbidity is that it is a widely measured water parameter and it also has a health related guidelines. In the GCDWQ, the turbidity in treated drinking water cannot exceed 1 NTU in 95% of the samples (Federal-Provincial Subcommittee on Drinking Water, 1993). The USEPA has more stringent turbidity regulations. The Surface Water Treatment Rule states that turbidities cannot exceed 0.5 NTU in 95% of the samples per month although in some cases less strict guidelines are allowable (LeChevallier and Norton, 1992).

5.3 Results

The two way analysis of variance (ANOVA) of all of the data is presented in Appendix D. The null hypothesis to be tested by the ANOVA in both situations is that the treatment means are all the same (Box *et al.*, 1978). The alternate hypothesis is that they are all different. An example in interpreting the ANOVA tables in the Appendix D is discussed with reference to Figure 5-7.

Figure 5-7. Example Two Way ANOVA Table

Source of Variation	SS	df	MS	F	P value	F_{crit}
Rows	0.28	2	0.14	0.996092	0.4456	6.94427
Columns	35.74	2	17.87	128.2336	0.0002	6.94427
Error	0.56	4	0.14			
Total	36.58	8				

List of Abbreviations Used:
SS = Sum of Squares
df = degrees of freedom
MS = Mean Square
F = F-test ratio
P value = probability value
F_{crit} = critical value with which to compare F

Rows = within treatments
Columns = between treatments

In order to determine whether the variation within and between treatments is significant, the F-test statistic from the ANOVA table is analyzed. The F_{crit} value listed is for the 95% confidence interval. Using the example above, $F<F_{crit}$ for the *rows* (i.e. Carbon filter A vs Carbon filter B vs Carbon Filter C) and so the null hypothesis is accepted. From this, it is established that there is no significant difference within the filters 55% (1 - P-value) of the time. The null hypothesis is rejected for the columns because $F<F_{crit}$. The columns in this case represent the variation between the different types of filters (Carbon vs Ceramic vs Plastic) and so the conclusion for this example is that the mean reduction is not the same when comparing the different types of filters.

A summary of the results obtained from the portable drinking water treatment filter analyses are presented in the pages that follow.

5.3.1 Turbidity Analysis

Table 5-3(a) contains the influent and effluent turbidity averages and standard deviations for each filter tested. Table 5-3(b) lists the associated percent reduction at each volume filtered. From these tables it is evident that the ceramic filter is the only filter that is capable of reaching the GCDWQ turbidity guideline of 1 NTU. These results are illustrated in Figure 5-8 and 5-9.

Table 5-3. Turbidity Levels and Percent Turbidity Reduction

(a)Turbidity (NTU)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Influent	33.30	-	30.30	-	30.30	-	25.93	0.45	25.93	0.45	31.08	0.91
Plastic	1.78	0.18	1.76	0.15	3.93	0.38	2.71	0.12	2.89	0.13	3.55	0.76
Carbon	1.28	0.08	1.88	0.12	3.07	0.06	1.99	0.15	2.06	0.36	3.12	0.45
Ceramic	0.94	0.41	0.54	0.04	0.40	0.10	0.23	0.08	0.34	0.08	0.56	0.19

(b) Turbidity Reduction (%)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Plastic	94.64	0.53	94.19	0.49	87.02	1.25	89.55	0.44	88.87	0.51	88.57	2.46
Carbon	96.17	0.24	93.80	0.40	89.88	0.19	92.34	0.58	92.05	1.38	89.97	1.46
Ceramic	97.19	1.23	98.21	0.13	98.68	0.33	99.10	0.29	98.68	0.31	98.20	0.61

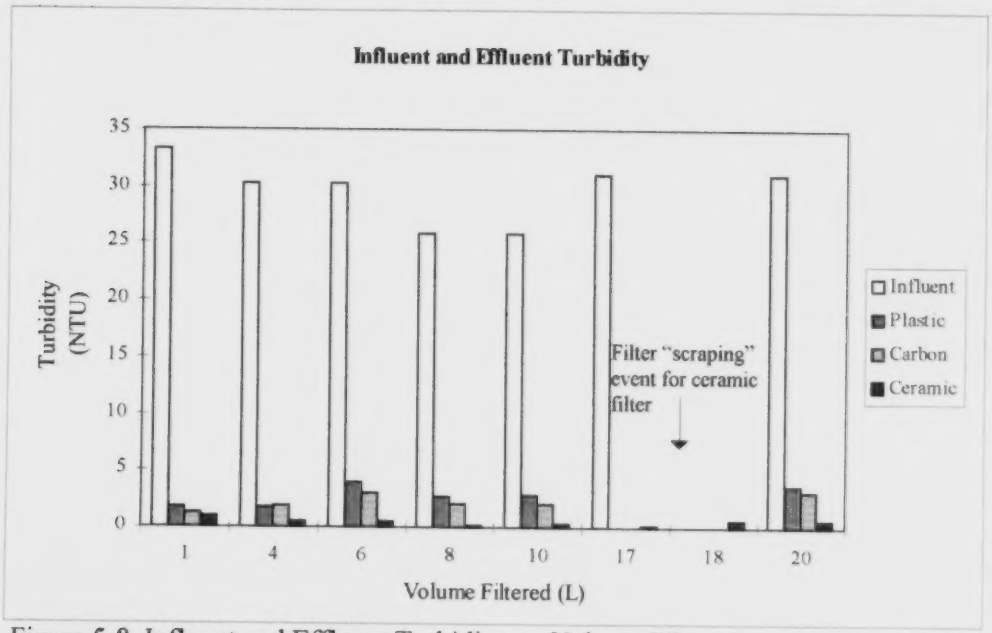


Figure 5-8. Influent and Effluent Turbidity vs. Volume Filtered.

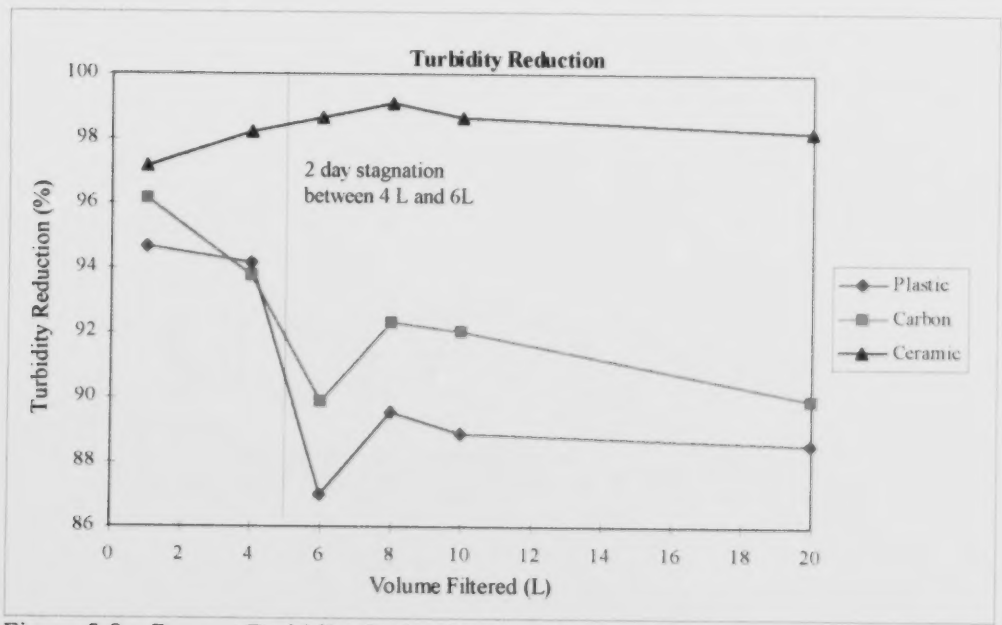


Figure 5-9. Percent Turbidity Reduction vs. Volume Filtered

Figure 5-8 illustrates the actual turbidity reduction for the filters. It is interesting to note that between 17 L and 18 L of water filtered, the pumping of the ceramic filters had become noticeably more difficult indicating that the pores had become blocked and the unit needed to be cleaned as explained by the manufacturer. This "regeneration" involved removing the filter element from the filter housing and scraping the ceramic filter under running water with the "regeneration brush" supplied until the bright natural colour of the ceramic reappeared. It is interesting to note that the turbidity following this regeneration is significantly higher than just prior to the scraping. This is typical of other filters after they have been backwashed. Another interesting feature to point out is in Figure 5-9. Between 4 L and 6 L volume filtered, all of the filters were left with water in them. The percent turbidity reduction dropped at this volume. This is possibly a result of bacterial growth in the filters during this time.

The turbidity reduction ANOVA results in Appendix D show that the variation within each filter type (i.e. comparing Carbon 1 vs Carbon 2 vs Carbon 3) is not significant. The variation between treatments, for all except the first litre of water filtered, is significant, and there is a difference between the filters.

5.3.2 Particle Analysis

As discussed, the particle counting machine is capable of counting particles in 8 particle size ranges. For the analysis of the data, only the four ranges chosen to be representative of bacteria (1 to 2 micron range), *Cryptosporidium* (3 to 4 micron range), *Giardia* (5 to 10 micron range), and larger particles (10 to 25 micron range) are presented.

5.3.2.1 Bacteria Particle Size Range (1 to 2 microns)

Table 5-4(a) contains the influent and effluent particle count averages and standard deviations for each filter tested. Table 5-4(b) lists the associated percent reduction at each volume filtered. The ceramic filter reduces the number of particles in this size range with the greatest efficiency followed by the carbon and then the plastic filter.

Table 5-4. Particle Counts and Percent Particle Reduction (1 to 2 microns)

(a) 1 micron to 2 micron Particle Count(particles/mL)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Influent	1216162	1511	1264985	14885	1157198	243443	1053074	175857	1053967	156725	1142509	128467
Plastic	38957	10611	38738	4565	143762	10610	105026	14912	89436	8312	107467	41091
Carbon	41425	2985	39866	8848	46863	6729	23674	5005	29574	9776	32013	10464
Ceramic	14077	10405	3035	4131	1022	123	344	301	689	184	135	40

(b) 1 micron to 2 micron Particle Reduction (%)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Plastic	96.80	0.87	96.94	0.36	87.58	0.92	90.03	1.42	91.51	0.79	90.59	3.60
Carbon	96.59	0.25	96.85	0.70	95.95	0.58	97.75	0.48	97.19	0.93	97.20	0.92
Ceramic	98.84	0.86	99.76	0.33	99.91	0.01	99.97	0.03	99.93	0.02	99.99	0.00

The average particle count per mL and percent reduction for 1 to 2 micron particle size range are presented in Figures 5-10 and 5-11. The particle count for the ceramic filter increases after the filter scraping event between 17 L and 18 L. This correlates with the higher turbidity at 18 L for the ceramic filter as well. There is a very interesting anomaly in Figure 5-11 that should be discussed. As mentioned, there was a 2 day stagnation period between 4 L and 6 L of water filtered. There is a dramatic drop from about 96% reduction to about 88% reduction for the carbon filter in this time span. Since the particle counter also counts the *E. coli* organisms that would likely be counted in this range, the data suggests that the bacteria have colonized the filter in this time and multiplied within it.

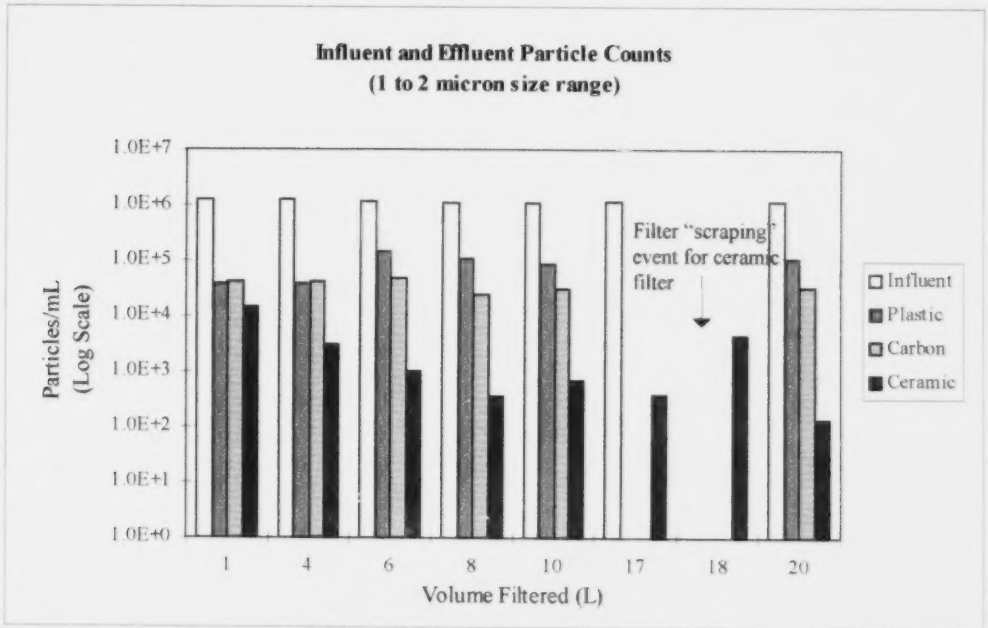


Figure 5-10. Influent and Effluent Particle Counts vs Volume Filtered (1 to 2 microns).

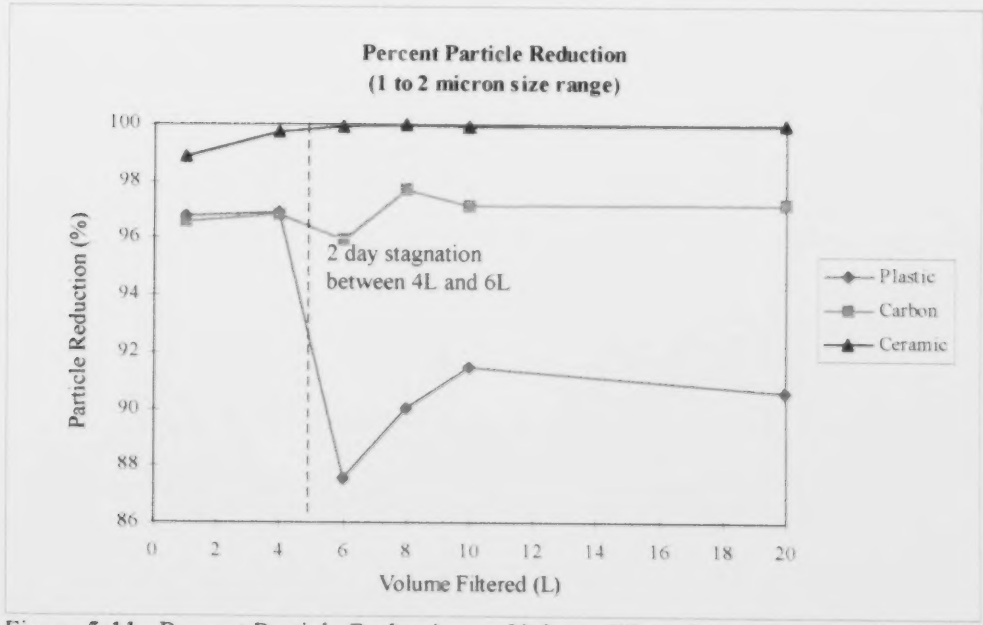


Figure 5-11. Percent Particle Reduction vs Volume Filtered (1 to 2 microns).

The bacterial colonization of activated carbon media is well documented (Geldreich and Reasoner, 1990; Geldreich *et al*, 1985) and these results seem to support colonization. There did not appear to be bacterial-size particle colonization in either of the ceramic or plastic filter to any appreciable extent.

The ANOVA results for the 1 to 2 micron particle analysis indicate that there is no significant difference between the sample means within treatments but there is between treatments.

5.3.2.2 Cryptosporidium Particle Size Range (4 to 5 microns)

Table 5-5(a) contains the influent and effluent particle count averages and standard deviations for each filter tested. Table 5-5(b) lists the associated percent reduction at each volume filtered. The ceramic filter reduces the number of particles in this size range with the greatest efficiency followed by the carbon and then the plastic filter. With the exception of the first litre of water filtered, the ceramic filter maintains a 3 log reduction. The other two filters have a 2 log removal of particles in this range.

Table 5-5. Particle Counts and Percent Particle Reduction (4 to 5 microns)

(a) 4 micron to 5 micron Particle Count (particles/mL)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Influent	77050	1073	76394	292	74658	17301	77512	15165	77532	10846	76811	12114
Plastic	389	327	265	156	762	770	259	38	288	138	238	50
Carbon	654	89	626	235	319	51	180	57	223	101	241	131
Ceramic	176	101	78	109	50	27	7	4	29	8	4	2

(b) 4 micron to 5 micron Particle Reduction (%)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Plastic	99.50	0.42	99.65	0.20	98.98	1.03	99.67	0.05	99.63	0.18	99.69	0.07
Carbon	99.15	0.12	99.18	0.31	99.57	0.07	99.77	0.07	99.71	0.13	99.69	0.17
Ceramic	99.77	0.13	99.90	0.14	99.93	0.04	99.99	0.00	99.96	0.01	99.99	0.00

Figure 5-12 and Figure 5-13 show the percent reduction and particle counts for this *Cryptosporidium* particle size range. Once again, the increase in number of particles in the ceramic filter at 18 L corresponds with the increased turbidity and the filter scraping event. There is also a decline in percent reduction for the carbon filter after the 2 day stagnation period. A similar trend was not evident in the other two filters.

The results from the ANOVA indicate that there is not a significant difference within filters. The assessment of the between filter performance shows that the difference in means is narrowing. A significant difference between filters at the 95% confidence interval was only found at 4 L, 8 L, and 20 L.

5.3.2.3 Giardia Particle Size Range (5 to 10 microns)

Table 5-6(a) contains the influent and effluent particle count averages and standard deviations for each filter tested. Table 5-6(b) lists the associated percent reduction at each volume filtered. The ceramic filter reduces the number of particles in this size range with the greatest efficiency followed by the carbon and then the plastic filter. With the exception of the first litre of water filtered, the ceramic filter maintains a 3 log reduction in this particle size range. The other two filters have a 2 log removal of particles in this range.

Figure 5-14 and 5-15 illustrate the average influent and effluent particle counts and the percent reduction for the 5 to 10 micron particle range. The increased number of particles associated with the ceramic filter scraping event is seen at 18 L for the ceramic unit. The carbon unit has a reduced percent removal of 5 to 10 micron particles at 6 L of water filtered.

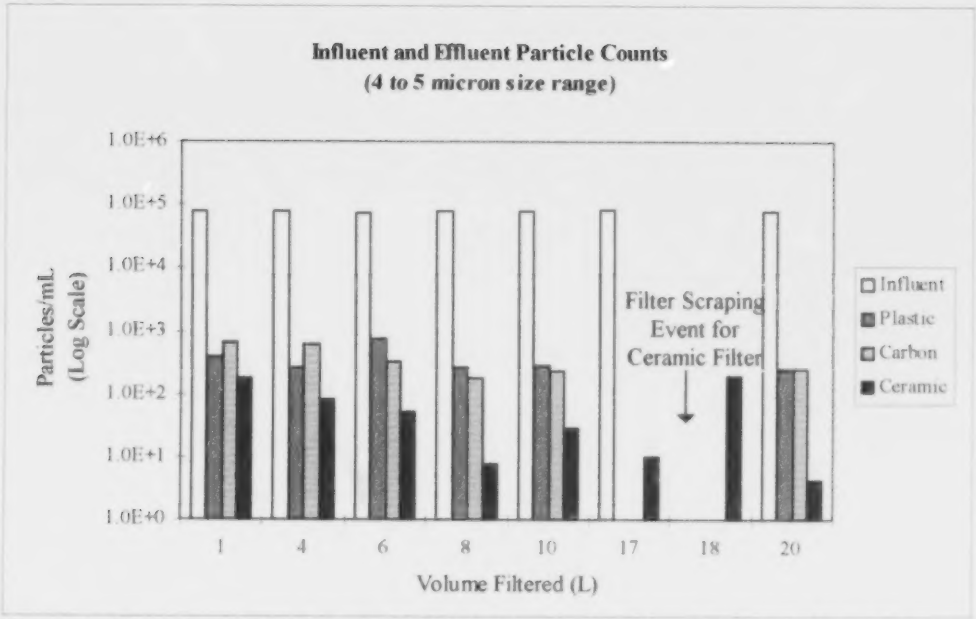


Figure 5-12. Influent and Effluent Particle Count vs Volume Filtered (4 to 5 microns)

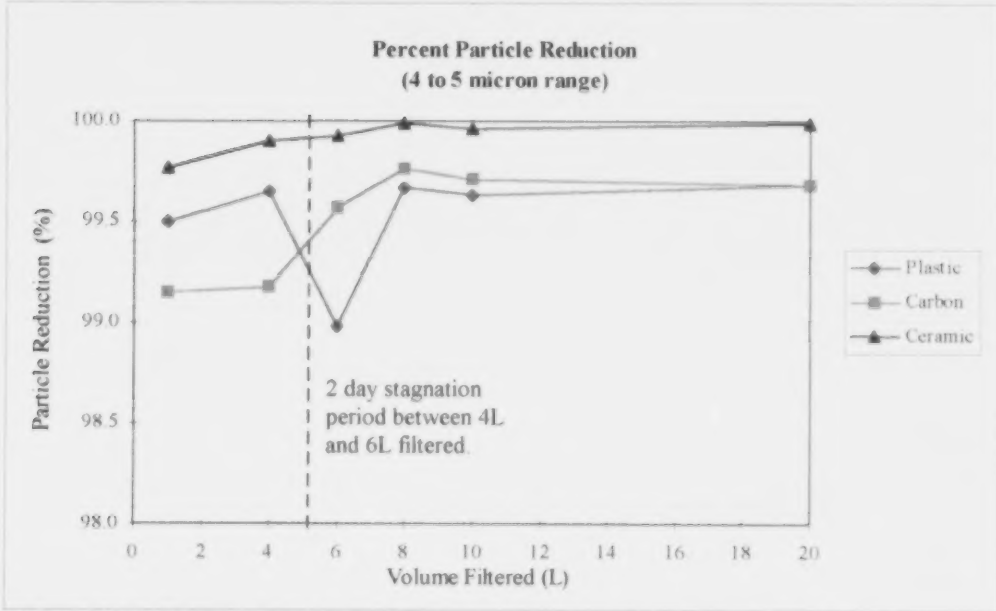


Figure 5-13. Percent Particle Reduction vs Volume Filtered (4 to 5 microns)

Table 5-6. Particle Counts and Percent Particle Reduction (5 to 10 microns)

(a) 5 micron to 10 micron Particle Count (particles/mL)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Influent	66405	855	65561	1063	61558	12455	67419	13884	67430	8891	69976	8653
Plastic	293	248	210	163	410	343	211	78	229	65	182	20
Carbon	356	26	377	167	181	39	92	35	139	62	199	93
Ceramic	121	82	48	53	52	29	6	4	27	7	4	3

(b) 5 micron to 10 micron Particle Reduction (%)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Plastic	99.56	0.37	99.68	0.25	99.33	0.56	99.69	0.11	99.66	0.10	99.74	0.03
Carbon	99.46	0.04	99.42	0.25	99.71	0.06	99.86	0.05	99.79	0.09	99.72	0.13
Ceramic	99.82	0.12	99.93	0.08	99.92	0.05	99.99	0.01	99.96	0.01	99.99	0.00

The ANOVA for this particle range indicates that a slight significant difference exists between the different filters at 8 L, 10 L and 20 L. There is no significant difference within treatments for this particle size range.

5.3.2.4 Larger Particle Size Range (10 to 25 microns)

Particle counts and percent particle reduction for the 10 to 25 micron particle size range are presented in Table 5-7(a) and 5-7(b). Once again the ceramic filter is most effective at removing particles in this size range. The average results obtained are plotted in Figure 5-16 and Figure 5-17. These figures illustrate the same trends as are evident in the other particle size analyses. The ceramic has the best overall removal capabilities and the plastic filter has the lowest percent reduction. There is also an increase in number of particles for the ceramic filter at 18 L corresponding with the filter scraping event.

The ANOVA on this particle size range indicate variation between filters at 8 L, 10 L and 20 L of water filtered. There is no significant within treatment variation.

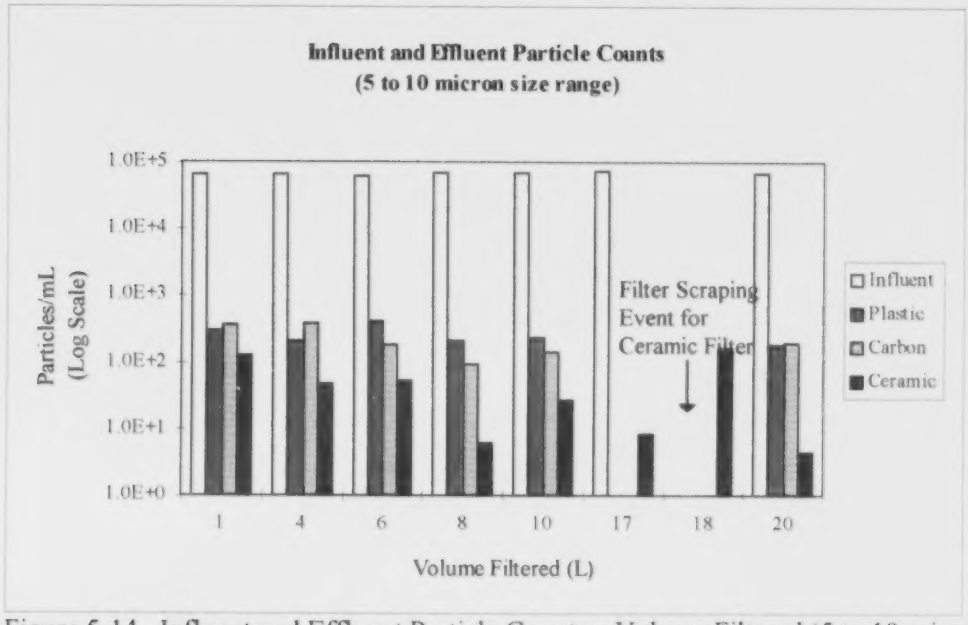


Figure 5-14. Influent and Effluent Particle Count vs Volume Filtered (5 to 10 microns)

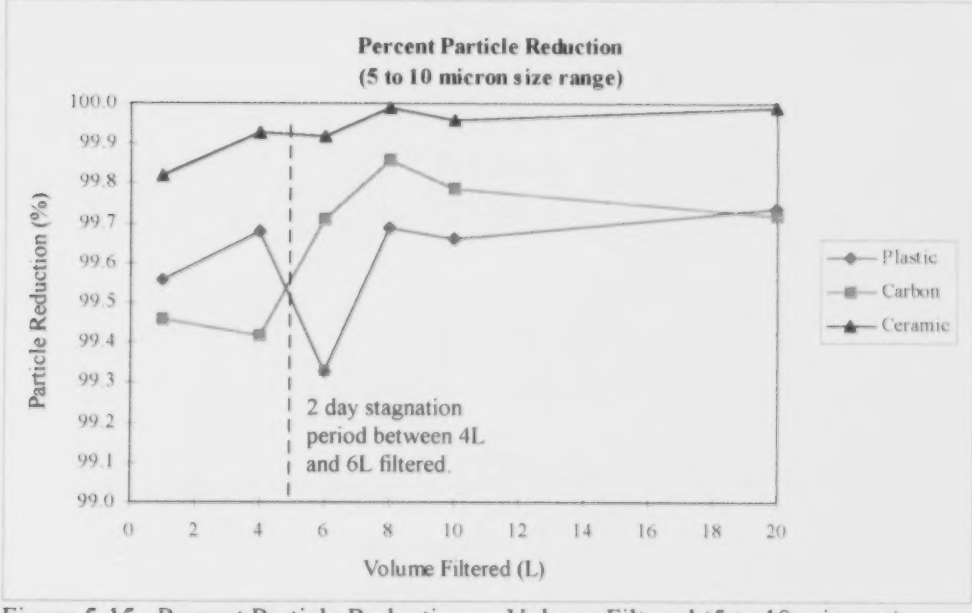


Figure 5-15. Percent Particle Reduction vs Volume Filtered (5 to 10 microns)

Table 5-7. Particle Counts and Percent Particle Reduction (10 to 25 microns)

(a) 10 micron to 25 micron Particle Count (particles/mL)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Influent	13867	304	13753	556	11956	3625	12659	3688	12661	799	14755	767
Plastic	58	53	28	25	47	25	58	29	105	47	57	18
Carbon	30	5	41	41	22	16	9	5	16	9	32	9
Ceramic	22	18	7	4	14	6	1	1	5	3	1	1

(b) 10 micron to 25 micron Particle Reduction (%)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Plastic	99.58	0.38	99.80	0.18	99.61	0.21	99.54	0.23	99.17	0.37	99.61	0.12
Carbon	99.79	0.04	99.70	0.30	99.81	0.13	99.93	0.04	99.88	0.07	99.78	0.06
Ceramic	99.84	0.13	99.95	0.03	99.88	0.05	99.99	0.01	99.96	0.03	99.99	0.00

5.3.3 Microbial Analysis

E. coli counts and *E. coli* reduction data are presented in Table 5-8(a) and 5-8(b).

Table 5-8. *E. coli* Counts and *E. coli* Percent Reduction

(a) *E. coli* Enumeration (cfu/100 mL)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Influent	5.0E+06	5.7E+05	4.1E+06	3.2E+05	6.5E+06	1.3E+06	5.7E+06	5.6E+05	5.8E+06	5.3E+05	6.7E+06	2.1E+06
Plastic	TNTC	NA	TNTC	NA	4.3E+06	3.9E+06	2.0E+06	3.2E+05	2.2E+06	5.0E+05	3.8E+06	9.7E+05
Carbon	2.3E+02	1.2E+02	1.9E+03	3.5E+02	1.3E+06	4.2E+05	1.0E+06	8.5E+04	7.4E+05	3.1E+05	1.5E+06	1.5E+06
Ceramic	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

(b) *E. coli* Reduction (%)

Volume Filtered (L)	1		4		6		8		10		20	
Statistic	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev	Avg	Std Dev
Plastic	-	-	-	-	33.02	59.91	64.68	5.64	62.19	8.55	43.28	14.60
Carbon	100.00	0.00	99.95	0.01	79.93	6.57	82.47	1.50	87.20	5.36	77.68	23.09
Ceramic	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00

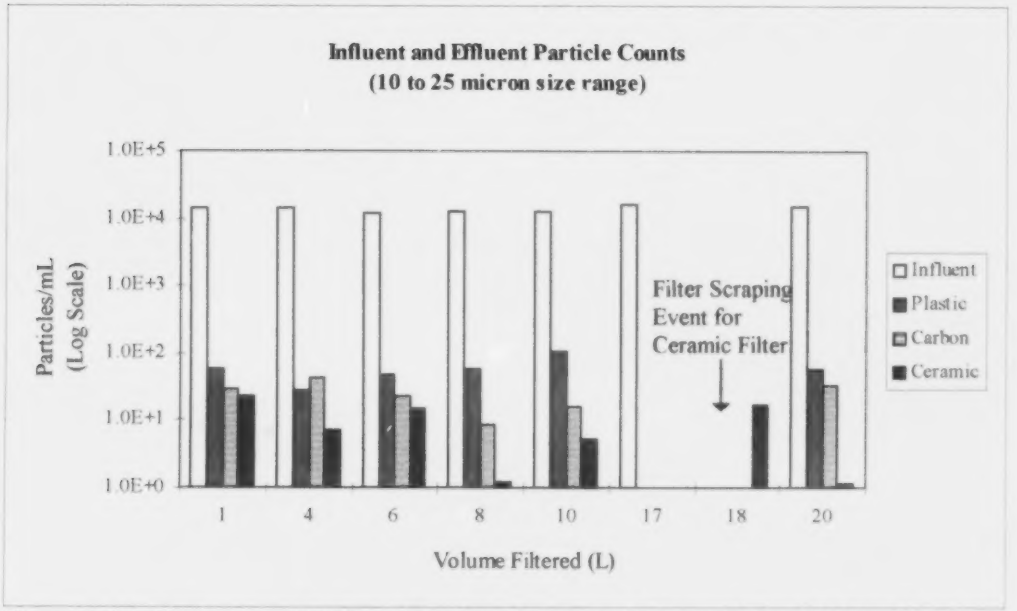


Figure 5-16. Influent and Effluent Particle Counts vs Volume Filtered (10 to 25 microns)

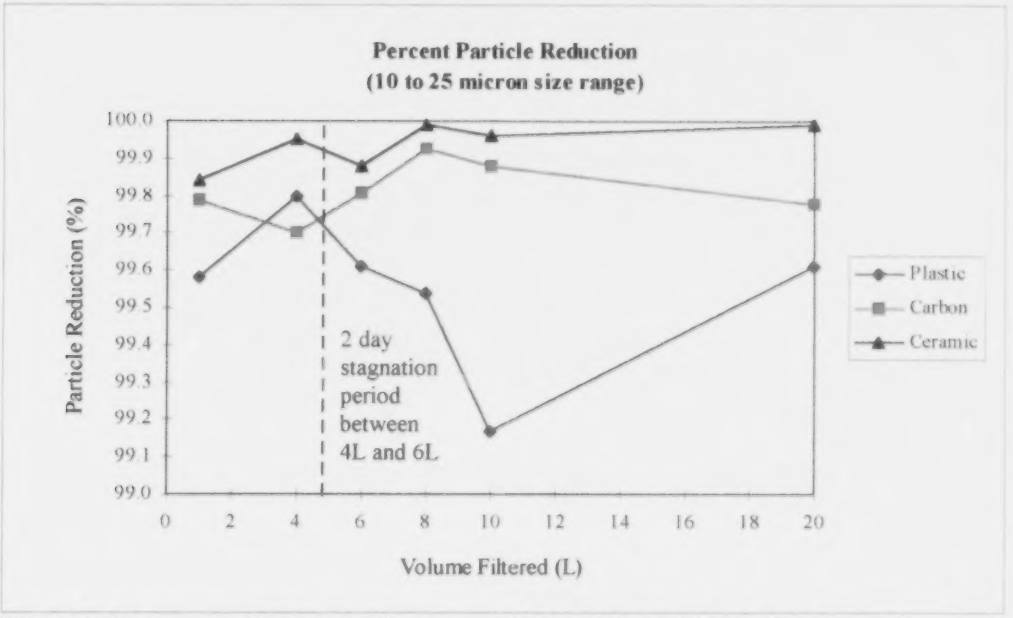


Figure 5-17. Percent Particle Reduction vs Volume Filtered (10 to 25 microns)

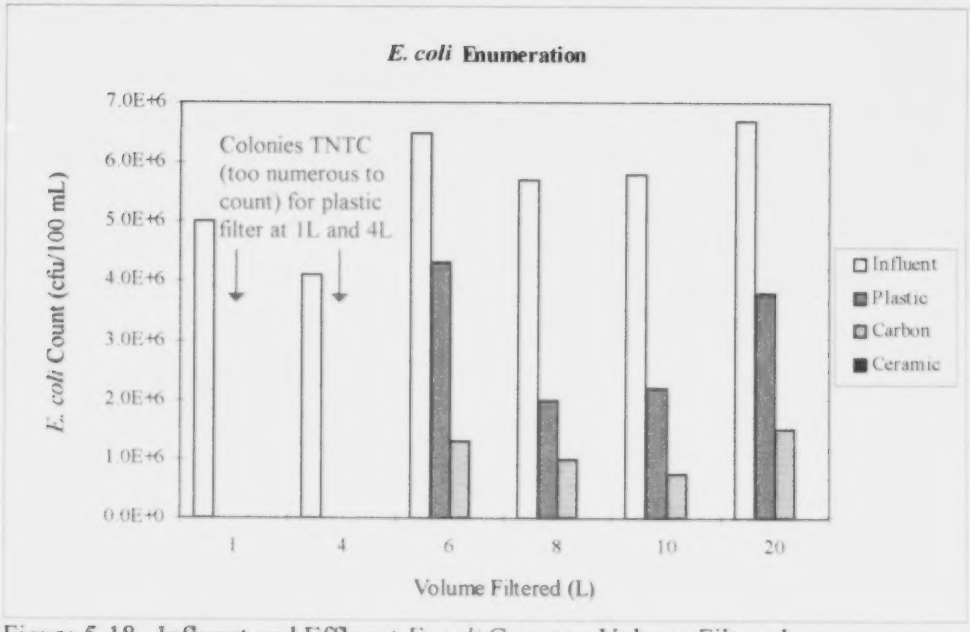


Figure 5-18. Influent and Effluent *E. coli* Count vs Volume Filtered

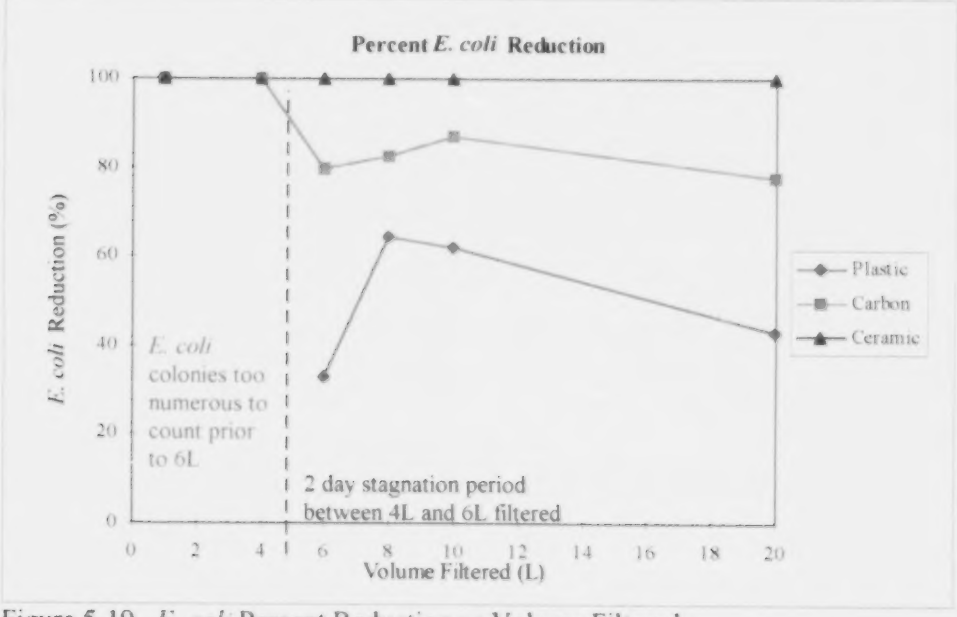


Figure 5-19. *E. coli* Percent Reduction vs Volume Filtered

Figure 5-18 and 5-19 illustrate the microbial reduction capabilities of the portable filters. The ceramic filter was effective at removing *E. coli* at all volumes. The carbon filter was less effective and the plastic filter was even less effective at removing microorganisms. Once again the ANOVA analysis showed that the variation within treatments was insignificant, but the variation between was significant.

5.4 Discussion

5.4.1 Assessment of Filter Effectiveness

Turbidity Analysis

The target influent turbidity was 30 NTU. Only the ceramic unit was able to reduce this influent turbidity to below the Canadian Drinking Water Quality Guideline value of 1 NTU. It also appears that there was a very slight initial conditioning period for the filters in which the turbidity reduction gets better.

The turbidity reduction for both the Carbon and the Plastic unit were less than for the Ceramic unit. Unlike the Ceramic filter, the percent turbidity reduction decreased for these other two units for the first 6 L and then seemed to level off somewhat from 10 L to 20 L. The Carbon and Plastic curves illustrate a minimum inflection point at 6 L. This low percent turbidity reduction is correlated with higher turbidity levels at 6 L of water filtered. Prior to collecting the 6 L sample, there was a 2 day stagnation period in which the filters were not used. It is possible that during this time, bacteria colonized the filter and were then sloughed off in the first litre of water collected after the stagnation period. These extra microorganisms may have contributed to the higher turbidities.

Microbial Analysis

The silver impregnated ceramic unit was very effective at removing the *E. coli* in the influent challenge water. Over the whole experimental test period, the effluent *E. coli* concentration was consistently <1 cfu/100 mL, which corresponds to a 6-log reduction. Regunathan and Beauman (1987) state that "*Escherichia coli* is readily killed by low levels of silver" and "there have been numerous unpublished reports of the bactericidal effect of silver on the common enteric pathogens, but these reports have not been confirmed." Even though the impregnated silver may inactivate *E. coli*, other heterotrophic bacteria are more resistant (Geldreich *et al.*, 1985). Measuring the HPC in the influent and effluent of these filters is a recommendation for further study.

The microbial removal in the other two units was less than ideal. Even the first litre of water filtered contained very high concentrations of *E. coli*. In the Plastic unit, the growth on the mEndo plate was so great that the colonies were *Too Numerous Too Count* (TNTC). For subsequent assays, appropriate dilutions were made. The Carbon unit has a slightly better percent removal than the Plastic unit over the course of the experiments, but by the eighth litre of water filtered, both the Carbon filter and the Plastic filter had less than a 1-log bacterial reduction.

Activated carbon filter media provides an ideal environment for bacterial growth because it chemically reduces chlorine, and bacteria can grow on the surface of the activated carbon (Drinking Water Health Effects Task Force, 1989). Culotta (1989) also talks about this bacterial contamination of activated carbon media, and explains that this is why activated carbon filters "should only be used to treat water that is microbiologically safe." Although it is not evident from the graphs and tables, it is interesting to note that one of the Plastic filters actually contributed *E. coli* to the effluent water at 6 L of water filtered. This certainly points to bacterial colonization and proliferation in this particular unit during the 2 day stagnation period prior to the 6 L collection.

Particle Analysis

As described above, the particle counts were divided into eight ranges: (1) 1 μ to 2 μ; (2) 2 μ to 3 μ; (3) 3 μ to 4 μ; (4) 4 μ to 5 μ; (5) 5 μ to 10 μ; (6) 10 μ to 25 μ; (7) 25 μ to 50 μ; and (8) greater than 50 μ. The smallest size particle that can be counted by the Hiac/Royco particle analyzer is 1μ. Therefore, the 0.2 μ and 0.5 μ claims made by the manufacturers of these devices was not tested. However, by looking at the particle counts in the 1 μ to 2 μ range, it is evident that some particles in this range still manage to squeeze through the filter media, so the absolute ratings supplied by the manufacturer are not necessarily accurate. Once again, the Ceramic filter was the most efficient and has the highest percent reduction. The percent particle reduction increased over time as the filter pores became clogged until after the cleaning event after Litre-17. After the filter scraping of this ceramic unit, the particle counts in all of the ranges measured increased. This corresponds to the increased turbidity also noticed at Litre-18. The average particle counts for the Carbon and the Plastic unit were typically greater than for the ceramic unit. This would be expected from the higher pore size ratings given by the manufacturers of these units.

5.4.2 Assessment of Experimental Protocol

The results of the Portable Drinking Water Treatment Filter Laboratory Testing just discussed were achieved under specific test conditions and are not necessarily definitive for all units under a variety of other conditions that may be experienced under actual operating conditions. Nonetheless, significant differences between different types of units were seen and certainly, the effectiveness of the Carbon and Plastic unit is questionable, because neither of these units had more than a 1-Log *E. coli* reduction after the sixth litre of water filtered.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Review of the literature found that little information was available on the use and quality of non-conventional drinking water, both within and outside of the study area. Compared to conventionally treated water, almost no information was available, which was somewhat surprising since it has been estimated that 25% of the population in the study area obtain their water from sources other than conventional treatment facilities. It would be expected that similar numbers would be found in other relatively remote areas in Canada.

The source of drinking water for the estimated 25% of people that do not obtain their drinking water from conventional drinking water treatment facilities are numerous. These people utilize non-conventional sources of water including: (1) self-hauled treated water, (2) untreated surface water, (3) ground water, (4) environmental sources of water such as rain water, snow water, ice water, and birch tree water (5) point-of-use treated water, and (6) bottled water. Population sub-groups that may be particularly predisposed to the utilization of non-conventional drinking water include:
(1) people living in rural remote areas, (2) people that consume the water for traditional or cultural purposes, (3) health conscious individuals and, (4) people that live off the land or are involved in wilderness activities.

It is not known to what extent these non-conventional sources of drinking water are treated; if at all. Some of the non-conventional drinking water treatment techniques that may be used by people living in remote areas include: (1) "point-of-use" disinfection methods; (2) "point-of-use" mechanical particle separation methods; and (3) "point-of-use" multi-barrier treatment processes:

1. Point-of-use disinfection methods include boiling the water, chlorinating the water with chlorine tablets or chlorine bleach, and treating the water with iodine tablets. Other point-of-use disinfection units may employ ultraviolet light or ozone as the disinfecting agent.
2. Point-of-use mechanical particle separation methods that may be utilized by people that do not receive their drinking water from conventional treatment facilities ranges from filtering the water with cloth and sand to more sophisticated reverse osmosis membrane filters, ion exchange units and activated carbon units. There are also portable drinking water treatment filters on the market that are designed to filter small quantities of water at the point-of-use. These filters contain a variety of media types ranging from polyethylene, activated carbon, ceramic, and iodinated resins.
3. Point-of-use multi-barrier treatment processes will typically employ several unit processes in the treatment sequence, utilizing both disinfection and mechanical separation techniques to obtain a high quality of drinking water. In some cases, small scale conventional drinking water treatment plants, called "package plants", may be installed in individual homes in remote areas.

Non-conventional sources of drinking water may also be used by people that receive drinking water from a conventional drinking water facility. These non-conventional sources have been labeled "special drinking water" by the people that collect it and are used for cooking and drinking purposes and for making tea. It is hypothesized that older members of the communities may engage in this practice more frequently than the younger generation. A more in-depth look into a particular communities drinking water practices is necessary to establish the extent of "special drinking water" usage by people that do have access to conventionally treated water.

Many people in the study area do not like the taste of chlorine in their drinking water. Some people have turned to additional treatment of the chlorinated water to try to get rid of this chlorine taste. Some of the methods used include boiling, aerating the water and treating it with a point of use filter. Although some of these point-of-use devices are very effective at removing the chlorine taste and odour in the drinking water, these devices have their limitations, particularly those that contain activated carbon. It is a well established fact that activated carbon units harbor bacterial growth and can lead to an increased number of microorganisms in the water that it treats if they are not properly maintained and if the filters are not replaced regularly. Public education about the reason that water is chlorinated may decrease the opposition to chlorination in some communities in the Northern Alberta.

There are many physical, chemical and microbiological parameters in the non-conventional drinking water samples tested that do not meet the guideline values recommended in the Guidelines for Canadian Drinking Water Quality. All of the surface water samples collected were positive for total coliforms which are used as an indicator of the pathogenicity of water. In addition, the general bacterial populations are fairly high. Furthermore, several of the physical and chemical guideline limits were exceeded in the samples tested. Based on this, drinking untreated surface water could potentially pose a serious threat to health. The analyses performed on the groundwater samples collected showed that the microbiological quality of the samples was satisfactory, but some chemical constituents, such as high ammonia, can be a cause for concern. The snow water samples collected showed that snow is not immune from contamination. The GCDWQ for Total Coliforms was exceeded for the snow samples as well as some other parameters. The quality of the bottled water samples collected met the health related guideline values. It should be noted that the background bacterial counts in bottled water is relatively high when compared to conventionally treated water. And finally, the point-of-use treatment device tested during the sampling component, showed that some of these units, especially those that employ activated carbon, have a tendency to foster bacterial

growth. Therefore, regular replacement of filter cartridges is necessary if these units are utilized.

From the portable drinking water treatment filter assessment it was found that two of the three units tested (plastic media and activated carbon media) were ineffective at removing *E. coli* bacteria after the first litre of water was filtered. Therefore, these units are not recommended as the sole treatment of contaminated drinking water for the wilderness excursions they are intended for. It has also been concluded from this analysis that these units do not always live up to the claims made by the manufacturers. Further laboratory testing of the silver impregnated ceramic unit is necessary before it can be condoned as a viable treatment option for those that live in remote areas in the study area or for those that live off of the land.

Initially, the assessment of non-conventional drinking water in the Northern River Basins Study was set out as a scientific-based study. However, it was quickly realized that there was also traditional and perhaps cultural aspects to the assessment of non-conventional drinking water; hence a large social scientific component. Therefore, although water samples can be analyzed by traditional scientific techniques, it is difficult to assess the overall impact that consuming non-conventional water will have when one must also consider the psychological edge that drinking "special water" may have for people. The problem is that it is difficult to incorporate belief systems into the scientific assessment of drinking water quality. Therefore, in approaching this study, researchers were not trying to find a reason to undermine traditional ways, rather, the focus was to try to gain an understanding about them.

There were many limitations in regards to the assessment of non-conventional drinking water in the study area as a result of the sociological component of this study. First, as is the case with any social scientific study, there are many potential errors in human inquiry and assessment. Second, in some areas in Northern Alberta, there was a language barrier between residents and researchers, particularly with elders in the native communities.

Third, many of the people interviewed seemed somewhat suspicious of the motives behind collecting the samples and some even openly expressed their concern that they feared that researchers would tell them that they could not drink their "special water" anymore. A fourth limitation with the collection of information for this assessment of non-conventional drinking water, was the relatively short amount of time spent in the study communities. To obtain a better understanding of traditional ways of obtaining drinking water and the extent of use, more time should be spent in the communities to get to know the residents, to gain their trust, and to actually participate in the activities being studied. In this way, a deeper understanding of the non-conventional drinking water treatment practices of Northern Alberta residents can be attained. Another alternative may be to more actively involve resident Community Health Representatives in a study of this nature in the future.

6.2 Recommendations

There are several recommendations for further study pertaining to the assessment of non-conventional drinking water supplies.

First, further testing of the portable silver impregnated ceramic filter is necessary before it can be recommended as a viable method of obtaining safe water during living off the land experiences. Another type of bacteria should be used in the challenge test water to see if the unit effectively removes other strains of bacteria. *Klebsiella terrigena* (ATCC-33257) is the bacterial organism suggested by the USEPA (1987) in the Guide Standard and Protocol for Testing Microbiological Water Purifiers. Furthermore, the capability of this unit to the reduction of viruses should also be assessed. In this instance, the USEPA (1987) recommends using Poliovirus Type 1 (Lsc) (ATCC-VR-59) and Rotavirus Strain SA-11 (ATCC-VR-899) or WA (ATCC-VR-2018). However, it may also be an effective alternative to test the units against a suitable bacterial enterovirus for an initial assessment.

Second, more samples of non-conventional drinking water supplies should be collected and analyzed for physical, chemical and microbiological parameters set in the GCDWQ. Samples of self-hauled treated water, untreated surface water (including lakes, rivers, dugouts), ground water (including springs and wells), environmental sources of water (including water from snow, ice, rain, birch trees, and the muskeg), point-of-use treated water (including point-of-use devices and point-of-use processes such as boiled water) and bottled water should be tested. These non-conventional drinking water supplies should be sampled more than one time per year. Perhaps, a sampling program could be implemented that would involve the collection of non-conventional samples on a quarterly basis from the same sampling location to see if there is a seasonal trend. This would also establish some baseline data on non-conventional drinking water sources in the study area.

Third, the input of Northern Alberta residents is important to the understanding of the utilization of non-conventional drinking water supplies in the study area. More information from these residents about their usage of alternative sources of drinking water would be beneficial in a future study. This could be done by a social scientific survey of a sample population from the study area. One method of collecting information would be by interviewing residents from each household of three or four selected communities. The selected communities would be chosen with the same criteria as in this thesis, although resident acceptance and study involvement would be a necessary criterion. The interview questions in a study such as this should be carefully designed so that the results could be analyzed statistically. The Community Health Representative would be involved in all of the interviews of the residents in a study of this nature.

Fourth, another aspect that should be further studied is the impact that the utilization of non-conventional drinking water supplies has on health. To do this, a matched case-control epidemiological study should be undertaken. Health record data would be used to match selected "cases" of diarrhea against "controls" of respiratory tract infections, for the selected study communities. Respiratory tract infections are suggested as a suitable "control" disease for health impact evaluation studies that link diarrheal disease to water

and sanitation exposure (Robinson and Heinke, 1990; Briscoe *et al.*, 1985). Once the appropriate number of cases and controls were established, each person's home could be randomly and blindly (i.e. blind to whether the individual was a case or a control) visited and interviewed regarding their drinking water practices. The data collected could be analyzed using Two by Two tables and odds ratios could then be calculated. In this manner, the significance that consuming non-conventional drinking water has on acquiring diarrhea could be established.

Finally, in the future, a community based approach to setting up water supply systems in remote Northern Alberta communities should be implemented based on a simple model such as the one illustrated in Figure 6-1.

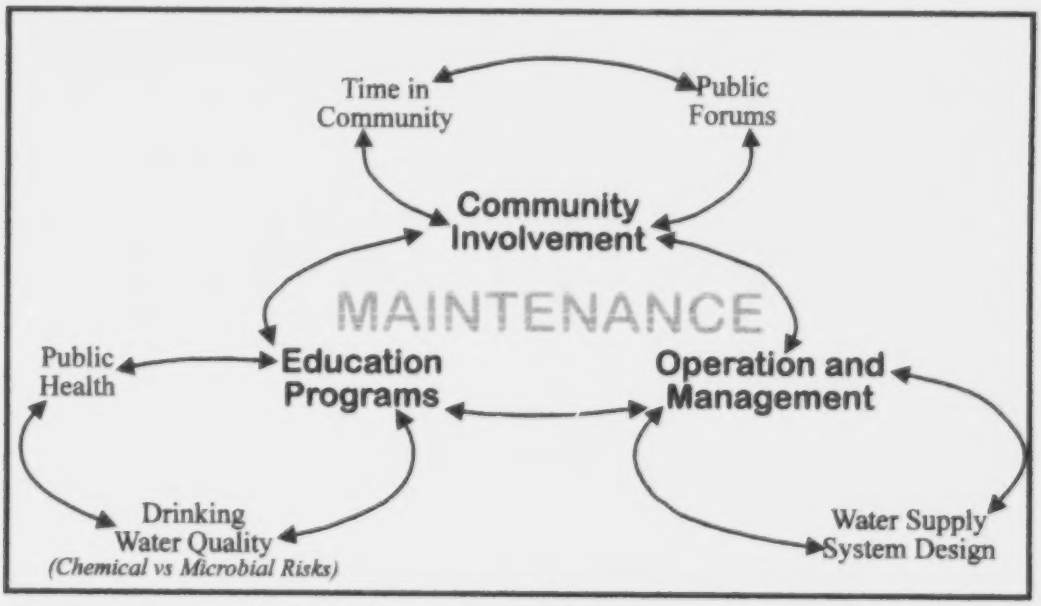


Figure 6-1. Elements in the Maintenance of a Safe Community Drinking Water Supply in Remote Areas in Northern Alberta

According to this figure, there are three main components involved in the maintenance of a community water supply system. Community involvement is of paramount importance to the success of any project in the community. If an outside *expert* is to be involved in the project, then that person should spend time in the community getting to know the

residents. During this time in the community, public forums should be held where questions, concerns and ideas can be discussed. The forums would also be a good time to educate residents regarding drinking water quality and general public health. Educational programs such as these comprise the second important component in this model. The third main component in the maintenance of an effective water supply program is the proper operation and maintenance of the system implemented. This is done through appropriate selection of community members to operate the designed system, and through continued community involvement in future decisions. If a model such as this is followed in the design of a water supply system for a remote area, a safe and sustainable supply of potable water is possible.

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APPENDIX A: Characteristics of Selected Waterborne Pathogens

ORGANISM	Pathogenicity			Vectors		Infectious Dose		Range of Symptoms	Potential Risk Groups
	None (*)	Opportunisitic	Direct	Water	Food	Normal	Compromised or Sensitive		
BACTERIA									
Acinetobacter species	+	+		+		U	N, ND	2, 4	E, H, IS
Aeromonas hydrophila		+		+		U	N, ND	3, 4, 5, 6, 7	CI, E, D, H, IC, ID, IS, S, O
Alcaligenes species	+	+		+		U	N, ND	2	IC, IS, ID
Bacillus cereus		+	+	+	+	$\approx 10^5$/g food or water	ND	5	CI, E, H, IC, IS, ID, O, S
Campylobacter jejuni		+	+	+	+	<500cfu to >5000cfu	ND	5, 9 (in special cases)	CI, E, H, IC, IS, ID, O, S
Campylobacter coli		+	+	+	+	<500cfu	ND	5, 9 (in special cases)	CI, E, H, IC, IS, ID, O, S
Citrobacter freundii		+	+	+	+	U	N, ND	3, 4, 5, 6	CI, E, H, IC, IS, ID, O, S
Clostridium perfringens		+	+	+	+	≈10/g food or water	N, ND	1 (gas gangrene), 2, 5, 6	CI, E, H, IC, IS, ID, O, S
Enterobacter aerogenes	+	+		+	+	U	N, ND	3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Enterobacter agglomerans	+	+		+	+	U	N, ND	3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Enterobacter cloacae		+		+	+	U	N, ND	3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Escherichia coli		+	+	+	+	? to $<10^8$cfu by ingestion	N, ND	2, 3, 4, 5, 6, 7, 8	CI, E, H, IC, IS, ID, O, S
Flavobacterium species	+	+		+		U	N, ND	1, 2, 3, 4	CI, E, IC, IS, ID, S
Hafnia alvei	+	+		?	?	U	N, ND	3, 4, 5, 6, 7	CI, E, IC, IS, ID, S
Klebsiella oxytoca	+	+		+		U	N, ND	3, 4, 6	CI, E, IC, H, IS, ID, S
Klebsiella ozonae	+	+		+		U	N, ND	3, 4, 6	CI, E, IC, H, IS, ID, S
Klebsiella pneumophila		+	+	+	+	U	N, ND	3, 4, 6	CI, E, IC, H, IS, ID, S
Legionella pneumophila		+	+	+		U	N, ND	4	CI, E, IC, H, IS, ID, S
Legionella species		+	+	+		U	N, ND	4	CI, E, IC, H, IS, ID, S
Mycobacterium avium-intracellulare		+		+		U	N, ND	4, 8, 9	E, IC, IS, ID, S

ORGANISM	Pathogenicity			Vectors		Infectious Dose		Range of Symptoms	Potential Risk Groups
	None (*)	Opportunistic	Direct	Water	Food	Normal	Compromised or Sensitive		
Mycobacterium chelonae	+	+		+		U	N, ND	4, 8, 9	E, IC, IS, ID, S
Mycobacterium fortuitum	+	+		+		U	N, ND	4, 8, 9	E, IC, IS, ID, S
Mycobacterium gordonae	+	+		+		U	N, ND	4, 8, 9	E, IC, IS, ID, S
Moraxella species	+	+		+		U	N, ND	2	CI, E, H, IC, ID, IS
Proteus species	+	+		+		U	N, ND	3, 6, 7	IC, ID, IS, S
Pasteurella multicida	+	+		+		U	N, ND	3, 4, 5, 6	IC, ID, IS, S
Pseudomonas aeruginosa		+	+	+	+	U	N, ND	1, 2, 3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Pseudomonas cepecia	+	+		+		U	N, ND	1, 2, 3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Pseudomonas fluorescens	+	+		+	+	U	N, ND	1, 2, 3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Salmonella species		+	+	+	+	100 - 1000 by ingestion	N, ND	5, 8 (in special cases)	CI, E, H, IC, IS, ID, O, S
Serratia species	+	+		+		U	N, ND	1, 2, 3, 4, 7	CI, E, H, IC, IS, ID, O, S
Shigella species		+	+	+	+	180 by ingestion	N, ND	5	CI, E, H, IC, IS, ID, O, S
Staphylococcus aureus	+	+	+	+	+	U	N, ND	1, 2, 3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Staphylococcus epidermidis	+	+		+		U	N, ND	1, 2	IC, ID, IS
Streptococcus faecalis	+	+		+	+	U	N, ND	5, 6	CI, E, H, IC, IS, ID, S
Streptococcus fecium	+	+		+	+	U	N, ND	5, 6	CI, E, H, IC, IS, ID, S
Vibrio fluvalis		+				U	N, ND	2, 5, 7	CI, E, H, IC, IS, ID, S
Vibrio alginolyticus		+				U	N, ND	2	CI, E, H, IC, IS, ID, S
Yersinia enterocolitica		+	+	+	+	U	N, ND	5	CI, E, H, IC, ID, IS, S
AMOEBA									
Acanthamoeba species		+	+	+	?	U	N, ND	2, 8 (eg. meningitis)	CI, E, H, IC, ID, IS, S
Naegleria fowlerii		+	+	+	?	U	N, ND	8 (eg. meningitis)	CI, E, H, IC, ID, IS, S
FUNGI									
Aspergillus species	+	+		+	+	U	N, ND	1, 4, 8, 9 (eg. allergic response)	CI, E, H, IC, ID, IS, S
Cephalosporium species	+	+		+		U	N, ND	1, 4, 8, 9 (eg. allergic	CI, E, H, IC, ID, IS, S

ORGANISM	Pathogenicity			Vectors		Infectious Dose		Range of Symptoms	Potential Risk Groups
	None (*)	Opportunistic	Direct	Water	Food	Normal	Compromised or Sensitive		
								response)	
Fusarium species	+	+		+		U	N, ND	1, 4, 8, 9 (eg. allergic response)	CI, E, H, IC, ID, IS, S
Penicillium species	+	+		+		U	N, ND	1, 4, 8, 9 (eg. allergic response)	CI, E, H, IC, ID, IS, S
Rhizopus species				+		U	N, ND	1, 4, 8, 9 (eg. allergic response)	CI, E, H, IC, ID, IS, S
VIRUSES									
Adenovirus		+		+		U	N, ND	2, 4, 5	CI, E, H, IC, ID, IS, S, O
Coxsackie virus		+		+		U	N, ND	2, 4, 5, 8, 9 (diabetes?)	CI, E, H, IC, ID, IS, S, O
Enterovirus		+		+		U	N, ND	2, 4, 5, 8	CI, E, H, IC, ID, IS, S, O
Hepatitis		+		+		U	N, ND	5, 8	CI, E, H, IC, ID, IS, S, O
Norwalk Virus		+		+		U	N, ND	5	CI, E, H, IC, ID, IS, S, O
Reovirus		+		+		U	N, ND	4, 5 (?)	CI, E, H, IC, ID, IS, S, O
Rotavirus		+		+		U	N, ND	5	CI, E, H, IC, ID, IS, S, O
PROTOZOA									
Cryptosporidium			+	+	?	1 cyst	1 cyst	5	CI, E, H, IC, ID, IS, S, O
Entamoeba histolytica			+	+	?	1 cyst	1 cyst	5	CI, E, H, IC, ID, IS, S, O
Giardia lamblia			+	+	?	1 cyst	1 cyst	5, 9 (eg. arthritis)	CI, E, H, IC, ID, IS, S, O

(Adapted from Emde et al., 1994)

1. * No documented pathogenicity for normally healthy persons
2. Risk Group Codes:

CI	Children and Infants	ID	Immunodeficient
E	Elderly	IS	Immunosuppressed
H	Healthy	S	Surgery
IC	Immunocompromised	O	Other (eg. previous illness, pregnancy etc)

3. Pathogenicity Codes:
   - U Infectious dose for normally healthy persons unknown.
   - ND Infectious dose for compromised persons not yet determined. In some cases the infectious dose may be as low as one organism .
   - N Nosocomial infections documented.
4. Range of Symptoms Codes:

1	Skin/Hair infection	6.	Genitourinary infection
2	Eye/Ear infection	7.	Wound infections
3	Bacteremia/Septecemia	8.	Other types of infections (meningitis)
4	Pneumonia/Respiratory Illness	9	Chronic infection (asthma, arthritis etc)
5	Gastrointestinal infection		

Appendix B: Guidelines for Canadian Drinking Water Quality, 1993
Maximum Acceptable Concentrations

"Maximum Acceptable Concentrations have been established for certain substances that are known or suspected to cause adverse effects on health"(Health and Welfare Canada, 1993). MAC's are derived to protect health based on the assumption of lifelong consumption of the substance at the established guideline concentration.

Microbiological Parameters	MAC
Total Coliforms[1]	0 cfu/100mL
Turbidity[2]	1 NTU

Radiological Parameters[3]	MAC (Bq/L)
Cesium-137	50
Iodine-131	10
Radium-226	1
Strontium-90	10
Tritium	40 000

Chemical Parameters	MAC (mg/L)
aldicarb	0.009
aldrin + dieldrin	0.0007
azinphos-methyl	0.02
barium	1.0
bendiocarb	0.04
benzene	0.005
benzo(a)pyrene	0.00001
cadmium	0.005
carbaryl	0.09
carbofuran	0.09
carbon tetrachloride	0.005
chlordane	0.007
chlorpyrifos	0.09
chromium	0.05
cyanide	0.2
diazinon	0.02
dicamba	0.12
1,2-diclorobenzene	0.2

Chemical Parameters (con't)	MAC (mg/L)
1,4-dichlorobenzene	0.005
DDT + metabolites	0.03
dichloromethane	0.05
2,4-dichlorophenol	0.9
diclofop-methyl	0.009
dinoseb	0.01
diquat	0.07
diuron	0.15
flouride	1.5
heptachlor+heptachlor epoxide	0.003
lead[4]	0.01
lindane	0.004
malathion	0.19
mercury	0.001
mehoxychlor	0.9
metribuzin	0.08
monochlorobenzene	0.08
nitrate[5]	45.0
nitrolotriacetic acid	0.4
parathion	0.05
pentachlorophenol	0.06
selenium	0.01
2,3,4,6-tetrachlorophenol	0.1
triallate	0.23
trichloroethylene	0.05
2,4,6-trichlorophenol	0.005
2,4,5-T	0.28
trihalomethanes	0.1
uranium	0.1

[1] This MAC is considered in compliance if there is less than 10cfu/100mL (and none of these are fecal coliforms) and if no consecutive samples show the presence of total coliforms. Community systems must also not have more than one sample per day with the presence of coliforms and cannot have coliforms present more than 10% of the time. The water should be immediately resampled to confirm positive coliform counts if: (1) the MAC is exceeded, (2) the total coliform background plate count is greater than 200 cfu/100mL or (3) the heterotrophic plate count is greater than 500cfu/mL.

[2] 5 NTU is permitted if it can be shown that disinfection is not compromised.

[3] Radiological guidelines are currently under review.

[4] At the point of consumption.

[5] Equivalent to 10mg/L nitrate as nitrogen.

Guidelines for Canadian Drinking Water Quality, 1993
Interim Maximum Acceptable Concentrations

Interim Maximum Acceptable Concentrations (IMAC) are set for substances that are assumed to have an adverse effect on health but for which there is insufficient toxicological data to set an MAC with reasonable certainty. Larger safety factors have been employed to compensate for the uncertainties for these substances.

Chemical Parameters	IMAC (mg/L)
arsenic	0.025
atrazine	0.06
boron	5.0
bromoxynil	0.005
cyanazine	0.01
1,2-dichloroethane	0.005
2,4-D	0.1
dimethoate	0.02
glyphosate	0.28

Chemical Parameters (con't)	IMAC (mg/L)
metolachlor	0.05
paraquat	0.01
phorate	0.002
picloram	0.19
simazine	0.01
temephos	0.28
terbufos	0.001
trifluralin	0.045

Guidelines for Canadian Drinking Water Quality, 1993
Aesthetic Objectives

Aesthetic Objectives are applied to parameters that affect the acceptablility of the water by consumers and so that a good quality of water can still be supplied. If the concentration is well above and aesthetic objective, there is a possibility of a health hazard. The AO parameters marked with an asterisk (*) also have assigned MAC guidelines.

Physical Parameters	AO
colour	≤15 TCU
odour	inoffensive
pH	6.5-8.5 units
taste	inoffensive
temperature	15°C
total dissolved solids (TDS)	≤500 mg/L
turbidity[1]	≤5NTU

Chemical Parameters	AO(mg/L)
chloride	≤250
copper[1]	≤1.0
1,2-dichlorobenzene *	≤0.003
1,4-dichlorobenzene *	≤0.001
2,4-dichlorophenol *	≤0.0003

Chemical Parameters (con't)	AO(mg/L)
ethylbenzene	≤0.0024
iron	≤0.3
manganese	≤0.05
monochlorobenzene *	≤0.03
pentachlorophenol *	≤0.03
sodium	≤200
sulphate	≤500
sulphide (as H_2S)	≤0.05
2,3,4,6-tetrachlorophenol *	≤0.001
toluene	≤0.024
2,4,6-trichlorophenol *	≤0.002
2,4,5-T *	≤0.02
total xylenes	≤0.3
zinc[1]	≤5.0

[1] At the point of consumption

APPENDIX C: Equipment and Supply Lists for Field Trips

Water Sampling Supplies for Field Trips

EQUIPMENT	NOTES	QUANTITY	PACKED
Coolers	Transport, sending samples back	as required +2	
Ice Packs	For sending samples back	≈ 16	
Packing Tape		2	
1 L Nalgene Bottles	Collecting Sample - 15 samples (2 for sending back, 1 for field analysis)	45	
500 ml Nalgene Collection Bottles	1 for Metals and 1 for Phys-Chem Samples	30	
glass pipettes and bulb	For Metals Acid	15	
Nitric Acid	Acidifying Metals Sample	1	
Little colored glass vials	THM Analysis	15	
Teflon caps for vials	Sealing THM vials	15	
1 L Coloured glass Bottles	THM Potential	15	
Labelling Tape		1	
Marking Pens		5	
Camera and film		1	
Lab Book		1	
Waterproof pen		1	
Interview Questions		1	
Maps of Area	High Level, John D'Or Prairie, Fox Lake	3	
Map of Alberta		1	

Physical-Chemical Analytical Supplies

EQUIPMENT	NOTES	QUANTITY	PACKED
Hach Spectrophotometer and Electirical Cord and Batteries	Conductivity, Colour, Nitrate, Ammonia, Chlorine	1	
Turbidimeter	Charge Battery	1	
pH Meter	Charge Battery	1	
CHEMICALS: Nitraver 5 and card Free and Combined Chlorine Ammonia powder pillows	Prairie Chem yellow and white	 1 pkg 1 pkg 1 pkg of each	
GLASSWARE: small pH beakers Ammonia graduated cylinders Odour Beaker and cap Caps for Ammonia beakers		 5 5 1 5	
DI Water	4L for 8 samples	8	
DI Water Dispenser	1L kind	1	
Fingernail Clippers		1	
Scissors and Swiss Army Knife		1	
Thermometer	Digital and Regular	2	
Stopwatch		1	
Kim Wipes		1 box	
Paper Towels			
Instruction Manuals	Spectrophotometer, Turbidimeter, pH Meter, relevant Standard Methods		

Microbial Analysis Supplies

EQUIPMENT	NOTES	QUANTITY	PACKED
Incubators	2 for 35°C and 1 for 44.5°C	3	
Thermometers	Aquarium thermometers	3	
Filtering pump		1	
Filtering tubing		3	
Filtering Flasks		2	
Extension Cord	(1 for Hach, 1 for filter, 1 for incubators if doing field microbial analysis)	3	
Pre-sterilized filters		8 or 15	
Black filter papers	HPC	1 box	
White filter papers	All others except HPC	1 box	
Flame		1	
Ethanol		1	
Forceps and small beaker		1	
Matches		2 pkg	
Sterile Peptone Wash Bottles	2 days ∴ 2 flasks	2	
Peptone Water	2 days ∴ 2 bottles	2	
Sterile Pipettes	72 + 8 initial pipettes	1 pkg 200	
Pipette Bulb		2	
Sterile Graduated Cylinders	8 samples + 2 extra	10 or 17	
Plastic Bags	For Plate disposal and for storing the Yeasts and Molds at room temperature for 1 week.	10	
Magnifying Glass/Microscope	To count colonies	1	
Counter		1	

Preparation of Microbiological Plates and Dilution Blanks

(Example for 8 water samples)

Parameter	Media	Incubation	Necessary for:	Quantity	Packed
Plate Preparation					
TC	mEndo	35°C, 24hr	2*3 plates*8 samples (25mL and 100mL dilution)	48	
FC	mFC	44.5°C, 24hr	3 plates * 8 samples (100 mL dilution)	24	
FS	mE	35°C, 48hr	3 plates * 8 samples (100 mL dilution)	24	
HPC	R_2A	35°C, 48hr & 20°C, 7days	2*3 plates * 8 samples (0.5mL and 1 mL dilution) + 8 for blanks	56	
Fungi	Rose Bengal	20°C, 7 days	2*3 plates * 8 samples (0.1mL and 0.5mL dilution)	48	
Yeast	Sabouran Dextros	20°C, 7 days	2*3 plates * 8 samples (0.1mL and 0.5 mL dilution)	48	
Dilution and Rinse Water Preparation					
90 ml blanks	Peptone Water		Initial dilution	10	
30 ml blanks	Peptone Water		Just for HPC and Fungi 6*8 + 3* 8 = 72	72	
Rinse Water	Peptone Water		To rinse the sides of the filter flask to ensure all microbes washed onto the filter.	4 bottles	

APPENDIX D: STATISTICAL ANALYSIS OF PORTABLE FILTER DATA

Turbidity Data

1L

a) Turbidity Level

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
NTU		1	1.98	1.24	0.57
NTU		2	1.64	1.37	1.38
NTU		3	1.73	1.22	0.86
NTU					
Average	33.30		1.78	1.28	0.94
Std Dev			0.18	0.08	0.41

b) Turbidity Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	94.05	96.28	98.29
% Removal	2	95.08	95.89	95.86
% Removal	3	94.80	96.34	97.42
Average		94.64	96.17	97.19
Std Dev		0.53	0.24	1.23

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	288.6186186	96.20620621	4.485867249
2	3	286.8168168	95.60560561	0.211322434
3	3	288.5585586	96.18618619	1.723344967
Plastic	3	283.9339339	94.64464464	0.279859439
Carbon	3	288.4984985	96.16616617	0.059819579
Ceramic	3	291.5615616	97.18718719	1.518936354

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.698195693	2	0.349097847	0.462529041	0.659625247	6.944276265
Columns	9.822034246	2	4.911017123	6.506737471	0.055275659	6.944276265
Error	3.019035051	4	0.754758763			
Total	13.53926499	8				

Turbidity Data

4L

a) Turbidity Level

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
NTU		1	1.93	1.94	0.50
NTU		2	1.66	1.96	0.58
NTU		3	1.69	1.74	0.55
NTU					
Average	30.30		1.76	1.88	0.54
Std Dev			0.15	0.12	0.04

b) Turbidity Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	93.63	93.60	98.35
% Removal	2	94.52	93.53	98.09
% Removal	3	94.42	94.26	98.18
Average		94.19	93.80	98.21
Std Dev		0.49	0.40	0.13

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	285.5775578	95.19251925	7.476754276
2	3	286.1386139	95.37953795	5.737999543
3	3	286.8646865	95.62156216	4.934519855
Plastic	3	282.5742574	94.19141914	0.238538705
Carbon	3	281.3861386	93.79537954	0.161204239
Ceramic	3	294.620462	98.20682068	0.017790558

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.277629523	2	0.138814762	0.996092054	0.445604621	6.944276265
Columns	35.74110986	2	17.87055493	128.2336083	0.000235838	6.944276265
Error	0.557437482	4	0.13935937			
Total	36.57617687	8				

All Turbidity Data

6L

a) Turbidity Level

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
NTU		1	4.20	3.00	0.30
NTU		2	4.10	3.10	0.40
NTU		3	3.50	3.10	0.50
NT					
Average	30.30		3.93	3.07	0.40
Std Dev			0.38	0.06	0.10

b) Turbidity Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	86.14	90.10	99.01
% Removal	2	86.47	89.77	98.68
% Removal	3	88.45	89.77	98.35
Average		87.02	89.88	98.68
Std Dev		1.25	0.19	0.33

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	275.2475248	91.74917492	43.45979152
2	3	274.9174917	91.63916392	39.90167994
3	3	276.5676568	92.18921892	28.90057983
Plastic	3	261.0561056	87.01870187	1.561212227
Carbon	3	269.6369637	89.8789879	0.036307261
Ceramic	3	296.039604	98.67986799	0.108921783

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.508301655	2	0.254150828	0.35	0.724309642	6.944276265
Columns	221.6195217	2	110.8097608	152.6	0.000167356	6.944276265
Error	2.904580887	4	0.726145222			
Total	225.0324042	8				

All Turbidity Data

8L

a) Turbidity Level

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
NTU	25.4	1	2.59	1.84	0.31
NTU	25.7	2	2.72	2.14	0.23
NTU	26.3	3	2.82	1.98	0.16
NTU	26.3				
Average	25.93		2.71	1.99	0.23
Std Dev	0.45		0.12	0.15	0.08

b) Turbidity Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	90.01	92.90	98.80
% Removal	2	89.51	91.75	99.11
% Removal	3	89.12	92.36	99.38
Average		89.55	92.34	99.10
Std Dev		0.44	0.58	0.29

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	281.7164899	93.90549662	20.09059216
2	3	280.3664417	93.45548055	25.25545495
3	3	280.8678881	93.62262938	27.50956493
Plastic	3	268.6403086	89.54676953	0.197885563
Carbon	3	277.0106075	92.33686917	0.335264763
Ceramic	3	297.2999036	99.09996786	0.083816191

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.310467074	2	0.155233537	0.672395274	0.560091009	6.944276265
Columns	144.7877581	2	72.39387906	313.5746509	4.01657E-05	6.944276265
Error	0.923465961	4	0.23086649			
Total	146.0216912	8				

Turbidity Data

10L

a) Turbidity Level

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
NTU	25.4	1	2.86	2.44	0.42
NTU	25.7	2	3.03	1.73	0.26
NTU	26.3	3	2.77	2.01	0.35
NTU	26.3				
Average	25.93		2.89	2.06	0.34
Std Dev	0.45		0.13	0.36	0.08

b) Turbidity Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	88.97	90.59	98.38
% Removal	2	88.31	93.33	99.00
% Removal	3	89.32	92.25	98.65
Average		88.87	92.05	98.68
Std Dev		0.51	1.38	0.31

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	277.9363549	92.64545162	25.31943299
2	3	280.6364513	93.54548377	28.57636154
3	3	280.2121504	93.40405014	22.78808483
Plastic	3	266.5959499	88.86531662	0.259383833
Carbon	3	276.1620058	92.05400193	1.9029747
Ceramic	3	296.027001	98.67566699	0.095719082

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	1.405533046	2	0.702766523	0.90369898	0.474413247	6.944276265
Columns	150.2571365	2	75.12856827	96.60905612	0.000411364	6.944276265
Error	3.110622183	4	0.777655546			
Total	154.7732918	8				

All Turbidity Data

20L

a) Turbidity Level

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
NTU	30.1	1	2.71	3.31	0.46
NTU	30.5	2	4.20	3.44	0.44
NTU	31.9	3	3.75	2.60	0.78
NTU	31.8				
Average	31.08		3.55	3.12	0.56
Std Dev	0.91		0.76	0.45	0.19

b) Turbidity Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	91.28	89.35	98.52
% Removal	2	86.48	88.93	98.58
% Removal	3	87.93	91.63	97.49
Average		88.57	89.97	98.20
Std Dev		2.46	1.46	0.61

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	279.1472	93.05	23.38
2	3	273.9984	91.33	40.93
3	3	277.0555	92.35	23.22
Plastic	3	265.6959	88.57	6.05
Carbon	3	269.9115	89.97	2.12
Ceramic	3	294.5937	98.20	0.38

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	4.4701926	2	2.235096319	0.708773466	0.54514824	6.94427627
Columns	162.45198	2	81.22598916	25.75764873	0.00519152	6.94427627
Error	12.613883	4	3.153470645			
Total	179.53605	8				

Average Particle Data **1 to 2 microns (bacteria range)**

1L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	51032	39282	23638
particles/mL		2	34720	44835	15598
particles/mL		3	31119	40158	2996
particles/mL					
Average	1216162		38957	41425	14077
Std Dev	1511		10611	2985	10405

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	95.80	96.77	98.06
% Removal	2	97.15	96.31	98.72
% Removal	3	97.44	96.70	99.75
Average		96.80	96.59	98.84
Std Dev		0.87	0.25	0.86

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	290.6301579	96.87671929	1.276999432
2	3	292.1759884	97.39199612	1.490529
3	3	293.8928279	97.96427598	2.539543305
Plastic	3	290.3901898	96.79672993	0.761289998
Carbon	3	289.7813399	96.59377997	0.060253617
Ceramic	3	296.5274445	98.84248149	0.731951784

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	1.775793989	2	0.887896995	2.667966115	0.183571223	6.944276265
Columns	9.282946663	2	4.641473332	13.94676821	0.01572949	6.944276265
Error	1.331196809	4	0.332799202			
Total	12.38993746	8				

Average Particle Data **1 to 2 microns (bacteria range)**

4L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	42702	44714	7797
particles/mL		2	33746	45230	915
particles/mL		3	39765	29653	395
particles/mL					
Average	1264985		38738	39866	3035
Std Dev	14885		4565	8848	4131

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	96.62	96.47	99.38
% Removal	2	97.33	96.42	99.93
% Removal	3	96.86	97.66	99.97
Average		96.94	96.85	99.76
Std Dev		0.36	0.70	0.33

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	292.4732022	97.4910674	2.692770486
2	3	293.6844432	97.8948144	3.305411346
3	3	294.4811221	98.16037405	2.612519583
Plastic	3	290.8130714	96.93769048	0.130255155
Carbon	3	290.5455741	96.84852471	0.489263975
Ceramic	3	299.280122	99.76004066	0.106666692

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.681504966	2	0.340752483	1.768152615	0.281710493	6.944276265
Columns	16.45053615	2	8.225268076	42.6806259	0.002003648	6.944276265
Error	0.770866678	4	0.19271667			
Total	17.9029078	8				

Average Particle Data **1 to 2 microns (bacteria range)**

6L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	148362	51902	1007
particles/mL		2	151296	49466	908
particles/mL		3	131628	39222	1152
particles/mL					
Average	1157198		143762	46863	1022
Std Dev	243443		10610	6729	123

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	87.18	95.51	99.91
% Removal	2	86.93	95.73	99.92
% Removal	3	88.63	96.61	99.90
Average		87.58	95.95	99.91
Std Dev		0.92	0.58	0.01

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	282.6070061	94.20233538	41.82922232
2	3	282.5726185	94.19087283	43.98904175
3	3	285.1364332	95.04547773	33.61960557
Plastic	3	262.7302048	87.57673494	0.840713379
Carbon	3	287.8508753	95.95029175	0.338107094
Ceramic	3	299.7349778	99.91165925	0.00011214

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	1.44136995	2	0.720684975	3.145395264	0.151085403	6.944276265
Columns	237.959244	2	118.979622	519.2808961	1.47203E-05	6.944276265
Error	0.916495276	4	0.229123819			
Total	240.3171092	8				

Average Particle Data **1 to 2 microns (bacteria range)**

8L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	89533	23442	165
particles/mL		2	106267	28791	175
particles/mL		3	119278	18789	692
particles/mL					
Average	1053074		105026	23674	344
Std Dev	175857		14912	5005	301

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	91.50	97.77	99.98
% Removal	2	89.91	97.27	99.98
% Removal	3	88.67	98.22	99.93
Average		90.03	97.75	99.97
Std Dev		1.42	0.48	0.03

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	289.2562173	96.41873909	19.38197382
2	3	287.1582667	95.71942224	27.16758834
3	3	286.8234374	95.60781246	36.80363039
Plastic	3	270.0801748	90.02672492	2.005049934
Carbon	3	293.2558341	97.7519447	0.225898574
Ceramic	3	299.9019125	99.96730418	0.000818268

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	1.159102813	2	0.579551407	0.701544626	0.548069582	6.944276265
Columns	163.4019544	2	81.70097719	98.89870134	0.000392906	6.944276265
Error	3.304430739	4	0.826107685			
Total	167.8654879	8				

Average Particle Data **1 to 2 microns (bacteria range)**

10L

a) Particle Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	87415	40353	498
particles/mL		2	98572	27088	866
particles/mL		3	82321	21282	701
particles/mL					
Average	1053967		89436	29574	689
Std Dev	156724		8312	9776	184

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	91.71	96.17	99.95
% Removal	2	90.65	97.43	99.92
% Removal	3	92.19	97.98	99.93
Average		91.51	97.19	99.93
Std Dev		0.79	0.93	0.02

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	287.8301065	95.94336882	17.04076062
2	3	287.9952603	95.99842009	23.02111974
3	3	290.1037072	96.70123572	16.22058737
Plastic	3	274.543067	91.51435568	0.621896033
Carbon	3	291.5819902	97.19399674	0.860259879
Ceramic	3	299.8040166	99.93467221	0.000305693

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	1.071342691	2	0.535671345	1.131552294	0.407887742	6.944276265
Columns	110.6713549	2	55.33567747	116.8911	0.000282984	6.944276265
Error	1.893580519	4	0.47339513			
Total	113.6362782	8				

Average Particle Data **1 to 2 microns (bacteria range)**
20L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	62963	36339	93
particles/mL		2	115472	39620	140
particles/mL		3	143967	20080	172
particles/mL					
Average	1142509		107467	32013	135
Std Dev	128467		41091	10464	40

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	94.49	96.82	99.99
% Removal	2	89.89	96.53	99.99
% Removal	3	87.40	98.24	99.98
Average		90.59	97.20	99.99
Std Dev		3.60	0.92	0.00

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	291.3002692	97.10008975	7.629318007
2	3	286.4130816	95.47102719	26.31972305
3	3	285.6264152	95.20880507	46.50335848
Plastic	3	271.7812545	90.59375151	12.93525316
Carbon	3	291.5940036	97.19800118	0.838796792
Ceramic	3	299.9645079	99.98816931	1.22465E-05

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	6.299562985	2	3.149781492	0.592940187	0.5949425	6.944276265
Columns	139.6562377	2	69.82811883	13.14500638	0.01743898	6.944276265
Error	21.24856141	4	5.312140353			
Total	167.2043621	8				

Average Particle Data **4 to 5 microns (*Cryptosporidium* range)**

1L

a) Particle Count

	Influent Water	Effluent			
		Filter #	Plastic	Carbon	Ceramic
particles/mL		1.0	759.3	655.9	257.5
particles/mL		2.0	266.7	742.5	205.7
particles/mL		3.0	140.3	564.7	63.4
particles/mL					
Average	77050		388.8	654.4	175.5
Std Dev	1073		327.1	88.9	100.5

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.01	99.15	99.67
% Removal	2	99.65	99.04	99.73
% Removal	3	99.82	99.27	99.92
Average		99.50	99.15	99.77
Std Dev		0.42	0.12	0.13

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	297.8290064	99.27633545	0.118251777
2	3	298.4231646	99.4743882	0.145495594
3	3	299.0026807	99.66756022	0.122781298
Plastic	3	298.4862404	99.49541346	0.180175692
Carbon	3	297.4521091	99.15070304	0.013315365
Ceramic	3	299.3165021	99.77216737	0.017018226

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.229597137	2	0.114798569	2.398865564	0.206718151	6.944276265
Columns	0.581635907	2	0.290817953	6.077019789	0.061313724	6.944276265
Error	0.191421429	4	0.047855357			
Total	1.002654473	8				

Average Particle Data **4 to 5 microns (*Cryptosporidium* range)**

4L

a) Particle Count

	Influent Water	Effluent			
		Filter #	Plastic	Carbon	Ceramic
particles/mL		1.0	224.3	879.7	204.5
particles/mL		2.0	132.5	579.9	17.3
particles/mL		3.0	437.3	417.1	12.9
particles/mL					
Average	76394		264.7	625.6	78.2
Std Dev	292		156.4	234.7	109.4

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.71	98.85	99.73
% Removal	2	99.83	99.24	99.98
% Removal	3	99.43	99.45	99.98
Average		99.65	99.18	99.90
Std Dev		0.20	0.31	0.14

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	298.2870884	99.42902946	0.252981315
2	3	299.0447238	99.6815746	0.151341643
3	3	298.8646476	99.6215492	0.098221496
Plastic	3	298.9604434	99.65348112	0.041895076
Carbon	3	297.5433086	99.18110287	0.094352241
Ceramic	3	299.6927078	99.89756927	0.020497945

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.104445951	2	0.052222976	0.999269671	0.444660917	6.944276265
Columns	0.796044333	2	0.398022167	7.616024837	0.043258239	6.944276265
Error	0.209044574	4	0.052261143			
Total	1.109534859	8				

Average Particle Data **4 to 5 microns (*Cryptosporidium* range)**

6L

a) Particle Count

	Influent Water	Effluent			
		Filter #	Plastic	Carbon	Ceramic
particles/mL		1.0	436.8	355.9	25.7
particles/mL		2.0	208.0	260.9	43.4
particles/mL		3.0	1641.7	338.6	79.4
particles/mL					
Average	74658		762.2	318.5	49.5
Std Dev	17301		770.2	50.6	27.4

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.41	99.52	99.97
% Removal	2	99.72	99.65	99.94
% Removal	3	97.80	99.55	99.89
Average		98.98	99.57	99.93
Std Dev		1.03	0.07	0.04

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	298.9037789	99.63459297	0.08512145
2	3	299.313691	99.77123034	0.023080956
3	3	297.241141	99.08038032	1.257645012
Plastic	3	296.9372834	98.97909445	1.064329399
Carbon	3	298.7202784	99.57342614	0.004592026
Ceramic	3	299.8010491	99.93368303	0.001346317

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.80309518	2	0.40154759	1.20094359	0.390394733	6.944276265
Columns	1.394254532	2	0.697127266	2.084959647	0.239709061	6.944276265
Error	1.337440304	4	0.334360076			
Total	3.534790017	8				

Average Particle Data **4 to 5 microns (*Cryptosporidium* range)**

8L

a) Particle Count

	Influent Water	Effluent		
		Filter #	Plastic	Carbon	Ceramic
particles/mL		1.0	252.0	226.3	5.6
particles/mL		2.0	300.1	197.1	5.1
particles/mL		3.0	224.5	117.1	11.4
particles/mL					
Average	77512		258.9	180.2	7.4
Std Dev	15165		38.2	56.5	3.5

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.67	99.71	99.99
% Removal	2	99.61	99.75	99.99
% Removal	3	99.71	99.85	99.99
Average		99.67	99.77	99.99
Std Dev		0.05	0.07	0.00

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	299.3756019	99.79186728	0.030535271
2	3	299.3520358	99.78401192	0.03731257
3	3	299.5444779	99.84815929	0.018896437
Plastic	3	298.9980474	99.66601582	0.002432442
Carbon	3	299.3026226	99.76754086	0.005319765
Ceramic	3	299.9714455	99.99048182	2.0665E-05

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.007345383	2	0.003672691	1.791477818	0.278254984	6.944276265
Columns	0.165288194	2	0.082644097	40.31241741	0.002234212	6.944276265
Error	0.008200361	4	0.00205009			
Total	0.180833938	8				

Average Particle Data **4 to 5 microns (*Cryptosporidium* range)**

10L

a) Particle Count

	Influent Water	Effluent		
		Filter #	Plastic	Carbon	Ceramic
particles/mL		1.0	236.3	284.5	20.2
particles/mL		2.0	182.7	276.9	36.3
particles/mL		3.0	444.5	106.1	29.3
particles/mL					
Average	77532		287.8	222.5	28.6
Std Dev	10846		138.3	100.9	8.1

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.70	99.63	99.97
% Removal	2	99.76	99.64	99.95
% Removal	3	99.43	99.86	99.96
Average		99.63	99.71	99.96
Std Dev		0.18	0.13	0.01

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	299.3022876	99.7674292	0.032968529
2	3	299.3603708	99.78679028	0.024464201
3	3	299.252023	99.75067635	0.081202951
Plastic	3	298.8862227	99.62874089	0.031823559
Carbon	3	299.1389992	99.71299975	0.016928461
Ceramic	3	299.8894656	99.96315519	0.000108413

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.001959726	2	0.000979863	0.040929458	0.96029353	6.944276265
Columns	0.181510221	2	0.090755111	3.790895161	0.119280263	6.944276265
Error	0.09576114	4	0.023940285			
Total	0.279231087	8				

Average Particle Data **4 to 5 microns (*Cryptosporidium* range)**
20L

a) Particle Count

	Influent Water	Effluent			
		Filter #	Plastic	Carbon	Ceramic
particles/mL		1.0	184.7	289.9	2.2
particles/mL		2.0	284.4	340.1	6.8
particles/mL		3.0	245.9	92.3	3.6
particles/mL					
Average	76811		238.3	240.8	4.2
Std Dev	12114		50.3	131.0	2.4

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.76	99.62	100.00
% Removal	2	99.63	99.56	99.99
% Removal	3	99.68	99.88	100.00
Average		99.69	99.69	99.99
Std Dev		0.07	0.17	0.00

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	299.3792239	99.79307464	0.035931821
2	3	299.1781234	99.72604112	0.054043441
3	3	299.5550215	99.85167383	0.025479189
Plastic	3	299.0690779	99.68969263	0.00428177
Carbon	3	299.0595647	99.68652156	0.029088358
Ceramic	3	299.9837262	99.99457541	9.42392E-06

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.023710937	2	0.011855469	1.101600371	0.415803664	6.944276265
Columns	0.187860736	2	0.093930368	8.727932292	0.034755852	6.944276265
Error	0.043048165	4	0.010762041			
Total	0.254619839	8				

Average Particle Data **5 to 10 microns (*Giardia* range)**

1L

a) Particle Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	577.2	359.2	189.4
particles/mL		2	180.2	380.4	144.2
particles/mL		3	122.0	328.8	30.6
particles/mL					
Average	66405		293.1	356.1	121.4
Std Dev	855		247.7	25.9	81.8

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.13	99.46	99.71
% Removal	2	99.73	99.43	99.78
% Removal	3	99.82	99.50	99.95
Average		99.56	99.46	99.82
Std Dev		0.37	0.04	0.12

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	298.3047035	99.43490117	0.085699764
2	3	298.9386882	99.64622941	0.03672473
3	3	299.2751409	99.75838031	0.052937061
Plastic	3	298.6757577	99.55858591	0.139164925
Carbon	3	298.3911423	99.46371409	0.001525494
Ceramic	3	299.4516327	99.81721088	0.015185481

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.161876208	2	0.080938104	2.160141057	0.231123379	6.944276265
Columns	0.200847519	2	0.100423759	2.680189854	0.182613571	6.944276265
Error	0.149875591	4	0.037468898			
Total	0.512599318	8				

Average Particle Data **5 to 10 microns (*Giardia* range)**

4L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	119.2	559.4	109.0
particles/mL		2	113.0	339.8	19.6
particles/mL		3	398.6	232.4	14.0
particles/mL					
Average	65561		210.3	377.2	47.5
Std Dev	1063		163.1	166.7	53.3

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.82	99.15	99.83
% Removal	2	99.83	99.48	99.97
% Removal	3	99.39	99.65	99.98
Average		99.68	99.42	99.93
Std Dev		0.25	0.25	0.08

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	298.798728	99.59957599	0.153837211
2	3	299.2794841	99.75982802	0.063080069
3	3	299.0162185	99.67207285	0.086556303
Plastic	3	299.0378939	99.67929796	0.06191258
Carbon	3	298.2740273	99.42467576	0.064633738
Ceramic	3	299.7825094	99.92750314	0.006609175

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.038637478	2	0.019318739	0.339411271	0.730881275	6.944276265
Columns	0.379273654	2	0.189636827	3.331732832	0.140709439	6.944276265
Error	0.22767351	4	0.056918377			
Total	0.645584642	8				

Average Particle Data **5 to 10 microns (*Giardia* range)**

6L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	292.9	223.0	27.5
particles/mL		2	141.1	145.6	44.7
particles/mL		3	796.3	173.5	84.6
particles/mL					
Average	61558		410.1	180.7	52.3
Std Dev	12455		343.0	39.2	29.3

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.52	99.64	99.96
% Removal	2	99.77	99.76	99.93
% Removal	3	98.71	99.72	99.86
Average		99.33	99.71	99.92
Std Dev		0.56	0.06	0.05

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	299.1172215	99.70574049	0.049923903
2	3	299.4617208	99.82057359	0.008578574
3	3	298.2870801	99.4290267	0.396887539
Plastic	3	298.0013529	99.33378431	0.310437404
Carbon	3	299.1193888	99.70646293	0.004054598
Ceramic	3	299.7452806	99.91509354	0.002262827

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.243066137	2	0.121533068	1.245077056	0.379848105	6.944276265
Columns	0.52033651	2	0.260168255	2.665361202	0.183776275	6.944276265
Error	0.390443524	4	0.097610881			
Total	1.15384617	8				

Average Particle Data **5 to 10 microns (*Giardia* range)**

8L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	162.7	119.6	3.9
particles/mL		2	300.6	103.8	4.4
particles/mL		3	170.4	52.2	10.4
particles/mL					
Average	67419		211.3	91.9	6.2
Std Dev	13884		77.5	35.2	3.6

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.76	99.82	99.99
% Removal	2	99.55	99.85	99.99
% Removal	3	99.75	99.92	99.98
Average		99.69	99.86	99.99
Std Dev		0.11	0.05	0.01

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	299.5754591	99.85848635	0.014840442
2	3	299.3937094	99.79790315	0.050004531
3	3	299.6544183	99.88480609	0.015162484
Plastic	3	299.0599661	99.68665536	0.013204098
Carbon	3	299.5912589	99.86375297	0.002733585
Ceramic	3	299.9723618	99.99078727	2.86141E-05

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.011915175	2	0.005957588	1.190480638	0.392959475	6.944276265
Columns	0.139997495	2	0.069998747	13.98756674	0.015649312	6.944276265
Error	0.020017419	4	0.005004355			
Total	0.171930089	8				

Average Particle Data **5 to 10 microns (*Giardia* range)**

10L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	255.9	173.0	19.2
particles/mL		2	154.7	177.0	30.1
particles/mL		3	274.9	68.2	31.0
particles/mL					
Average	67430		228.5	139.4	26.7
Std Dev	8891		64.6	61.7	6.5

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.62	99.74	99.97
% Removal	2	99.77	99.74	99.96
% Removal	3	99.59	99.90	99.95
Average		99.66	99.79	99.96
Std Dev		0.10	0.09	0.01

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	299.3355325	99.77851084	0.031717558
2	3	299.4635656	99.82118854	0.013785767
3	3	299.4452257	99.81507525	0.037991743
Plastic	3	298.9834578	99.6611526	0.009189125
Carbon	3	299.3798528	99.79328428	0.008370771
Ceramic	3	299.8810132	99.96033775	9.43319E-05

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.003195715	2	0.001597857	0.199030951	0.827174823	6.944276265
Columns	0.134877393	2	0.067438697	8.400241484	0.036980531	6.944276265
Error	0.032112742	4	0.008028185			
Total	0.17018585	8				

Average Particle Data **5 to 10 microns (*Giardia* range)**
20L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	163.0	252.8	3.5
particles/mL		2	181.7	251.0	7.3
particles/mL		3	201.9	91.6	2.3
particles/mL					
Average	69976		182.2	198.5	4.4
Std Dev	8653		19.5	92.6	2.6

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.77	99.64	99.99
% Removal	2	99.74	99.64	99.99
% Removal	3	99.71	99.87	100.00
Average		99.74	99.72	99.99
Std Dev		0.03	0.13	0.00

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	299.4007717	99.80025723	0.032556462
2	3	299.3713015	99.79043383	0.032207225
3	3	299.5772036	99.85906786	0.020416381
Plastic	3	299.2188091	99.73960303	0.00077323
Carbon	3	299.1491882	99.71639608	0.017493737
Ceramic	3	299.9812794	99.99375981	1.3576E-05

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.008265819	2	0.00413291	0.58425457	0.598948395	6.944276265
Columns	0.142064869	2	0.071032435	10.04159976	0.027586183	6.944276265
Error	0.028295266	4	0.007073817			
Total	0.178625955	8				

Average Particle Data **10 to 25 microns (larger particle range)**

1L

a) Particle Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	119.1	31.1	38.5
particles/mL		2	26.1	23.9	24.9
particles/mL		3	27.9	33.5	3.8
particles/mL					
Average	13867		57.7	29.5	22.4
Std Dev	604		53.2	5.0	17.5

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.14	99.78	99.72
% Removal	2	99.81	99.83	99.82
% Removal	3	99.80	99.76	99.97
Average		99.58	99.79	99.84
Std Dev		0.38	0.04	0.13

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	298.6384066	99.54613553	0.123904086
2	3	299.4590733	99.81969109	6.31E-05
3	3	299.5290465	99.8430155	0.012954443
Plastic	3	298.7509057	99.58363524	0.147086047
Carbon	3	299.3609971	99.78699904	0.001298057
Ceramic	3	299.5146235	99.83820785	0.015901525

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.163514388	2	0.081757194	1.981309686	0.252352767	6.944276265
Columns	0.108786389	2	0.054393194	1.318168562	0.36329808	6.944276265
Error	0.16505687	4	0.041264218			
Total	0.437357647	8				

Average Particle Data **10 to 25 microns(larger particle range)**

4L

a) Particle Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	9.1	87.9	11.9
particles/mL		2	18.7	20.1	4.7
particles/mL		3	56.5	15.3	4.0
particles/mL					
Average	13753		28.1	41.1	6.9
Std Dev	556		25.1	40.6	4.4

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.93	99.36	99.91
% Removal	2	99.86	99.85	99.97
% Removal	3	99.59	99.89	99.97
Average		99.80	99.70	99.95
Std Dev		0.18	0.30	0.03

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	299.2073723	99.73579078	0.105681688
2	3	299.6829313	99.89431043	0.003835735
3	3	299.4480713	99.81602377	0.040373346
Plastic	3	299.386244	99.79541467	0.033200529
Carbon	3	299.1026669	99.70088898	0.087153767
Ceramic	3	299.849464	99.94982133	0.001011866

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.037694617	2	0.018847309	0.367684731	0.713530011	6.944276265
Columns	0.094743832	2	0.047371916	0.924160085	0.467797291	6.944276265
Error	0.205037707	4	0.051259427			
Total	0.337476156	8				

Average Particle Data **10 to 25 microns(larger particle range)**

6L

a) Particle Count

	Influent	Effluent		
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	73.9	40.3	11.8
particles/mL		2	25.8	10.1	9.9
particles/mL		3	40.9	16.5	21.5
particles/mL					
Average	11956		46.9	22.3	14.4
Std Dev	3625		24.6	15.9	6.2

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.38	99.66	99.90
% Removal	2	99.78	99.92	99.92
% Removal	3	99.66	99.86	99.82
Average		99.61	99.81	99.88
Std Dev		0.21	0.13	0.05

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	298.9460729	99.64869097	0.067523393
2	3	299.6166095	99.87220315	0.005846652
3	3	299.3407083	99.7802361	0.011618848
Plastic	3	298.8242539	99.60808465	0.042235603
Carbon	3	299.4401948	99.81339828	0.017750007
Ceramic	3	299.6389419	99.87964729	0.002718718

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.075719756	2	0.037859878	3.047753357	0.156987018	6.944276265
Columns	0.120288884	2	0.060144442	4.841680292	0.085454402	6.944276265
Error	0.0496889	4	0.012422225			
Total	0.245697541	8				

Average Particle Data **10 to 25 microns(larger particle range)**

8L

a) Particle Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	55.5	10.9	0.2
particles/mL		2	30.6	12.1	0.6
particles/mL		3	88.2	3.1	2.7
particles/mL					
Average	12659		58.1	8.7	1.2
Std Dev	3688		28.9	4.9	1.4

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.56	99.91	100.00
% Removal	2	99.76	99.90	100.00
% Removal	3	99.30	99.98	99.98
Average		99.54	99.93	99.99
Std Dev		0.23	0.04	0.01

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	299.4733435	99.82444783	0.053727525
2	3	299.6579274	99.88597582	0.014318954
3	3	299.257425	99.75247501	0.151167272
Plastic	3	298.6231183	99.54103944	0.052006646
Carbon	3	299.7929624	99.93098748	0.001490145
Ceramic	3	299.9726152	99.99087174	0.000113732

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.026788244	2	0.013394122	0.666102457	0.562738102	6.944276265
Columns	0.357994698	2	0.178997349	8.901708753	0.033656646	6.944276265
Error	0.080432804	4	0.020108201			
Total	0.465215746	8				

Average Particle Data **10 to 25 microns(larger particle range)**

10L

a) Particle Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	140.6	20.3	3.1
particles/mL		2	51.1	20.5	3.3
particles/mL		3	123.0	5.7	9.1
particles/mL					
Average	12661		104.9	15.5	5.2
Std Dev	799		47.4	8.5	3.4

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	98.89	99.84	99.98
% Removal	2	99.60	99.84	99.97
% Removal	3	99.03	99.95	99.93
Average		99.17	99.88	99.96
Std Dev		0.37	0.07	0.03

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	298.7044275	99.56814251	0.350019803
2	3	299.4076188	99.80253961	0.036564787
3	3	298.9110936	99.63703122	0.277880217
Plastic	3	297.5142083	99.17140278	0.140134049
Carbon	3	299.6318783	99.87729275	0.004493817
Ceramic	3	299.8770534	99.95901781	0.000728754

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.087080679	2	0.043540339	0.855272635	0.490642117	6.944276265
Columns	1.125297053	2	0.562648527	11.052231	0.023479589	6.944276265
Error	0.203632561	4	0.05090814			
Total	1.416010293	8				

Average Particle Data **10 to 25 microns(larger particle range)**
20L

a) Particle Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
particles/mL		1	61.4	39.9	1.0
particles/mL		2	38.2	33.5	1.8
particles/mL		3	72.7	22.5	0.4
particles/mL					
Average	14755		57.4	32.0	1.1
Std Dev	767		17.6	8.8	0.7

b) Particle Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	99.58	99.73	99.99
% Removal	2	99.74	99.77	99.99
% Removal	3	99.51	99.85	100.00
Average		99.61	99.78	99.99
Std Dev		0.12	0.06	0.00

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	299.3064084	99.7688028	0.043156043
2	3	299.5015275	99.83384248	0.017972505
3	3	299.3515086	99.78383621	0.063011215
Plastic	3	298.8320682	99.61068938	0.014245192
Carbon	3	299.3492905	99.78309684	0.003557867
Ceramic	3	299.9780858	99.99269527	2.29338E-05

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	0.006956791	2	0.003478396	0.484874987	0.647814855	6.944276265
Columns	0.219584332	2	0.109792166	15.3046066	0.013357849	6.944276265
Error	0.028695195	4	0.007173799			
Total	0.255236318	8				

Average Microbial Data (using Geomean)

1L

a) Microbial Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
cfu/100mL		1	TNTC	1.5E+02	0
cfu/100mL		2	TNTC	3.7E+02	0
cfu/100mL		3	TNTC	1.8E+02	0
cfu/100mL			TNTC		
Average	5.0E+06		TNTC	2.3E+02	0
Std Dev	5.7E+05			1.2E+02	0

b) Microbial Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	TNTC	100.00	100
% Removal	2	TNTC	99.99	100
% Removal	3	TNTC	100.00	100
Average		TNTC	100.00	100
Std Dev			0.00	0

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	2	199.9970445	99.99852223	4.36761E-06
2	2	199.9926632	99.99633158	2.69146E-05
3	2	199.9964759	99.99823795	6.20967E-06
Carbon	3	299.9861835	99.9953945	5.67601E-06
Ceramic	3	300	100	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	5.67603E-06	2	2.83801E-06	1.000007691	0.499998077	19.00002644
Columns	3.18159E-05	1	3.18159E-05	11.21072015	0.078800891	18.51276465
Error	5.67598E-06	2	2.83799E-06			
Total	4.31679E-05	5				
Total	6390.280503	8				

Average Microbial Data (using Geomean)

4L

a) Microbial Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
cfu/100mL		1	TNTC	2.3E+03	0
cfu/100mL		2	TNTC	1.7E+03	0
cfu/100mL		3	TNTC	1.7E+03	0
cfu/100mL					
Average	4.1E+06		TNTC	1.9E+03	0
Std Dev	3.2E+05			3.5E+02	0

b) Microbial Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	TNTC	99.94	100
% Removal	2	TNTC	99.96	100
% Removal	3	TNTC	99.96	100
Average		TNTC	99.95	100
Std Dev			0.01	0

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	2	199.9438573	99.97192864	0.001576002
2	2	199.9582476	99.97912382	0.00087163
3	2	199.9590975	99.97954877	0.000836505
Carbon	3	299.8612025	99.95373416	7.3345E-05
Ceramic	3	300	100	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	7.3345E-05	2	3.66725E-05	1.000000033	0.499999992	19.00002644
Columns	0.003210792	1	0.003210792	87.55315283	0.011229605	18.51276465
Error	7.3345E-05	2	3.66725E-05			
Total	0.003357482	5				

Average Microbial Data (using Geomean)

6L

a) Microbial Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
cfu/100mL		1	8.8E+06	1.0E+06	0
cfu/100mL		2	2.4E+06	1.1E+06	0
cfu/100mL		3	1.8E+06	1.8E+06	0
cfu/100mL					
Average	6.5E+06		4.3E+06	1.3E+06	0
Std Dev	1.3E+06		3.9E+06	4.2E+05	0

b) Microbial Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	-35.88	83.84	100
% Removal	2	62.09	83.61	100
% Removal	3	72.84	72.35	100
Average		33.02	79.93	100
Std Dev		59.91	6.57	0

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	147.9571532	49.31905106	5509.428558
2	3	245.7019753	81.90065844	361.4290593
3	3	245.1864465	81.72881551	250.437047
Plastic	3	99.05108	33.01702667	3588.931028
Carbon	3	239.794495	79.93149834	43.13982348
Ceramic	3	300	100	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	2111.9835	2	1055.99175	0.819844196	0.503048392	6.944276265
Columns	7090.431127	2	3545.215564	2.752412038	0.177105406	6.944276265
Error	5152.158202	4	1288.03955			
Total	14354.57283	8				

Average Microbial Data (using Geomean)

8L

a) Microbial Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
cfu/100mL		1	1.9E+06	1.0E+06	0
cfu/100mL		2	2.4E+06	1.1E+06	0
cfu/100mL		3	1.8E+06	9.0E+05	0
cfu/100mL					
Average	5.7E+06		2.0E+06	1.0E+06	0
Std Dev	5.6E+05		3.2E+05	8.5E+04	0

b) Microbial Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	67.21	81.99	100
% Removal	2	58.22	81.26	100
% Removal	3	68.61	84.14	100
Average		64.68	82.47	100
Std Dev		5.64	1.50	0

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	249.2043953	83.06813177	269.6477488
2	3	239.4838861	79.82796202	437.8673405
3	3	252.753201	84.25106699	246.3083084
Plastic	3	194.0461186	64.68203955	31.77942788
Carbon	3	247.3953637	82.46512124	2.240767238
Ceramic	3	300	100	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	31.46189329	2	15.73094665	1.720239809	0.289013494	6.944276265
Columns	1871.068298	2	935.5341492	102.3042746	0.000367668	6.944276265
Error	36.57849694	4	9.144624236			
Total	1939.108689	8				

Average Microbial Data (using Geomean)

10L

a) Microbial Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
cfu/100mL		1	2.8E+06	1.1E+06	0
cfu/100mL		2	2.0E+06	5.7E+05	0
cfu/100mL		3	1.8E+06	5.6E+05	0
cfu/100mL					
Average	5.8E+06		2.2E+06	7.4E+05	0
Std Dev	5.3E+05		5.0E+05	3.1E+05	0

b) Microbial Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	52.52	81.01	100
% Removal	2	65.29	90.22	100
% Removal	3	68.76	90.37	100
Average		62.19	87.20	100
Std Dev		8.55	5.36	0

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	233.534599	77.84486635	571.0749943
2	3	255.5073354	85.16911179	320.402507
3	3	259.1252513	86.37508376	256.0279131
Plastic	3	186.563212	62.18773735	73.08290374
Carbon	3	261.6039736	87.20132454	28.72786269
Ceramic	3	300	100	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	127.8635487	2	63.93177437	3.375579492	0.138423369	6.944276265
Columns	2219.252845	2	1109.626422	58.5879593	0.001089651	6.944276265
Error	75.75798411	4	18.93949603			
Total	2422.874378	8				

Average Microbial Data (using Geomean)

20L

a) Microbial Count

	Influent	Effluent			
	Water	Filter #	Plastic	Carbon	Ceramic
cfu/100mL		1	2.9E+06	3.2E+06	0
cfu/100mL		2	3.7E+06	7.9E+05	0
cfu/100mL		3	4.8E+06	4.2E+05	0
cfu/100mL					
Average	6.7E+06		3.8E+06	1.5E+06	0
Std Dev	2.1E+06		9.7E+05	1.5E+06	0

b) Microbial Reduction

	Effluent			
	Filter #	Plastic	Carbon	Ceramic
% Removal	1	56.99	51.22	100
% Removal	2	44.91	88.11	100
% Removal	3	27.94	93.71	100
Average		43.28	77.68	100
Std Dev		14.60	23.09	0

c) Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	208.2122356	69.40407853	710.418341
2	3	233.0270265	77.6756755	840.3046159
3	3	221.6460429	73.88201429	1592.98575
Plastic	3	129.8463914	43.28213047	213.0388291
Carbon	3	233.0389136	77.67963786	532.94952
Ceramic	3	300	100	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P value*	*F crit*
Rows	102.8630906	2	51.43154528	0.148098888	0.866864964	6.944276265
Columns	4898.303805	2	2449.151903	7.052416416	0.048812488	6.944276265
Error	1389.113608	4	347.2784019			
Total	6390.280503	8				